UNIVERSITY OF CALIFORNIA
COLLEGE OF AGRICULTURE
AGRICULTURAL EXPERIMENT STATION
BERKELEY, CALIFORNIA

OBSERVATIONS ON USE OF IRRIGATION WATER IN COACHELLA VALLEY, CALIFORNIA

ARTHUR F. PILLSBURY

BULLETIN 649
JUNE, 1941

UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA

CONTENTS

PAGE

Introduction 3

Description of the valley and its agriculture 5

  Location and climate 5

  Water supply 5

  Formation and soils 5

  Development of the agriculture 7

Soil-moisture technique employed 7

  Plant-soil-water relations 7

  Selection of plots 8

  Methods 9

  Limitations and accuracy of work 10

  Example of method of interpreting data 11

Results of soil-moisture investigations in date orchards 14

  Description of the date plots 14

  Soil characteristics of the date plots 21

  Transpirational use 22

  Irrigation efficiency 22

  Water applied 22

  Root distribution 23

  Growth rates 23

Results of soil-moisture investigations in grapefruit orchards 26

  Description of the grapefruit plots 26

  Soil characteristics of the grapefruit plots 27

  Water use and root distribution 27

  Growth rates 28

Results of soil-moisture investigations in vineyards 30

Effectiveness of irrigation treatments in controlling the concentration of salts in the soil solution 33

Present applications of water on farms 37

  Methods of measurement 37

  Classes of crops 39

  Summary of the records 39

Crop and well survey 43

  Total "draft" on ground waters 43

Summary and conclusions 46

OBSERVATIONS ON USE OF IRRIGATION WATER IN COACHELLA VALLEY, CALIFORNIA[1]

ARTHUR F. PILLSBURY[2]

INTRODUCTION

THIS BULLETIN deals essentially with the results of a four-year irrigation investigation in Coachella Valley, California, carried on under a joint project of the Division of Irrigation of the College of Agriculture and the Division of Irrigation of the Bureau of Agricultural Engineering, United States Department of Agriculture.[3]

The greater part of the work dealt with soil-moisture sampling to determine transpirational use, root distribution, and irrigation efficiency for Deglet Noor date trees, Marsh grapefruit trees, and Thompson Seedless grapevines. No differential treatments were attempted, the objective being to establish the plots in successful commercial plantings where growers appeared to have obtained consistently good yields of high-quality fruit. At the same time all practical measures were taken to assure the adequacy of the irrigation treatments employed.

Also, records were obtained from as many farms as possible of the amounts of water now applied in growing all the principal commercial crops. These records were obtained by months and are for periods of one to eight years.

Under an informal coöperative agreement with the Coachella Valley County Water District in which that organization did most of the original field work, a crop and well survey was made between the fall of 1936 and the spring of 1937. From these data a crop and well map was later prepared for the Valley.

"Use of water" in this bulletin refers to the rates at which water is utilized in irrigation. Whether that rate signifies plant use or the amounts applied will be designated in the text.

---

[1] Received for publication June 28, 1940.

[2] Assistant Irrigation Engineer in the Experiment Station.

[3] The investigation was under the active supervision of Frank Adams, Professor of Irrigation Investigations and Practice, during 1932, and of Martin R. Huberty, Associate Professor of Irrigation Investigations and Practice, from 1936 to 1939. The Bureau of Agricultural Engineering contributed to the project through W. W. McLaughlin, Chief of the Irrigation Division. Mr. O. C. Compton, Associate in the Experiment Station, Riverside, made chemical analyses of the soil solutions. The Bureau of Plant Industry provided laboratory space at their experiment station near Indio. The Coachella Valley County Water District provided the services of Mr. Washington McIntyre who did the original field work on the crop and well survey.

TABLE 1

SUMMARY OF CLIMATOLOGICAL DATA FOR INDIO, CALIFORNIA*

	Years of record	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	April	May	June	Season
Temperature,† degrees Fahrenheit														
Average	61	93.2	91.9	85.8	75.1	63.0	55.4	53.7	59.1	65.1	72.2	79.1	87.7	73.4
Average maximum	25	106.5	105.5	100.6	90.7	80.4	70.7	69.6	74.8	79.6	86.2	92.7	102.1	88.3
Average minimum	25	77.7	76.2	69.3	57.8	46.4	38.7	38.6	44.5	49.8	56.7	63.4	71.6	57.6
Highest	34	125	120	118	110	101	90	92	97	104	110	121	121	125
Lowest	34	62	48	48	36	23	17	16	21	27	35	33	55	16
Precipitation, inches														
Average	60	0.08	0.21	0.20	0.20	0.18	0.49	0.68	0.51	0.27	0.11	0.05	0.01	2.99
Maximum record	60	1.87	3.61	2.10	2.74	1.10	3.44	6.01	3.16	2.06	2.17	0.57	0.32	7.09
Minimum record	60	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.18
Maximum season (1926–27)	..	trace	0.10	0.10	trace	0.01	3.38	0.07	3.15	0.28	trace	0.0	0.0	7.09
Minimum season (1894–95)	..	0.07	trace	trace	trace	0.03	0.04	0.03	trace	0.01	0.0	0.0	0.0	0.18

* Data from U. S. Weather Bureau, summarized to 1939. Observer: U. S. Bureau of Plant Industry.

† All frost data are based on 26 years' records. A minimum of 32° Fahrenheit is assumed as "killing."
Average date of the last killing frost in the spring—February 5.
Average date of the first killing frost in the autumn—December 4.
Average length of the growing season in days—302.
Date of the latest killing frost in the spring—March 16.
Date of the earliest killing frost in the autumn—November 12.

DESCRIPTION OF THE VALLEY AND ITS AGRICULTURE[4]

Location and Climate.—Coachella Valley is located in the south-central part of Riverside County. It is bounded on the southeast by the Salton Sea; on the northeast by the Little San Bernardino Mountains; on the southwest by the Santa Rosa Mountains; and on the west by the San Jacinto Mountains and San Gorgonio Pass.

Elevations of the valley floor range from about 245 feet below sea level at Salton Sea to about 500 feet above sea level at Palm Springs. Most of the agricultural development is below an elevation of about 250 feet above sea level.

The climate is arid. Rainfall averages only 3 inches per year at Indio. Summer temperatures are high, and winters are normally warm. A brief summary of climatological data is shown in table 1.

Through most of the year, and especially during extremely hot weather, relative humidity is normally low, but long periods of high humidity (50 to 80 per cent) accompanied by moderately high temperatures (maximums from 100° to 110° Fahrenheit) are common between July and September. Thunder showers are apt to occur in the surrounding mountains during such periods, and these sometimes extend down into the valley. Rainfall intensities may be extremely high, but usually localized to some small portion of the region. Damaging flash floods sometimes occur in a small area while the rest of the valley will receive little or no rain. Rainfall is normally not sufficient to provide any appreciable soil moisture for the growing of agricultural crops, summer or winter.

Water Supply.—The present water supply is derived exclusively from wells except for a few small springs, and some surface-water diversion in the Palm Springs and Whitewater areas. The ground water feeding these wells is under pressure, but water reaches the ground surface and flows from wells only in the lower trough of the valley. Water is pumped in the principal agricultural areas.

The Bureau of Reclamation, United States Department of the Interior, is at present constructing the Coachella branch of the All-American Canal. This canal will bring water from the Colorado River to supplement the present supply.

Formation and Soils.—Part of Coachella Valley is cut off from the Gulf of California only by the alluvial cone of the Colorado River in Imperial Valley. It is not thought that the valley has been an arm of the Gulf, but the valley itself dropped as the mountains pushed upwards.[5]

---

[4] Mendenhall, W. C. Ground waters of the Indio region, California, 1908. U. S. Geological Survey Water-supply Paper 225:1–56.

[5] Buwalda, J. P., and W. L. Stanton. Geological events in the history of the Indio Hills and Salton Basin, Southern California. Science 71:104–6. 1930.

The soils of the Valley are of recent alluvial nature, derived from granitic rock. In texture they grade from the coarse material found at the tops of the alluvial cones to the fine clays found in the lower trough of the valley. Such gradation is not, however, uniform. Because of the extremely varying nature of the flood flows carrying suspended material and bed load, and because of progressive movement of part of the material from flood to flood, there is a mixture of materials. Deposits of sands, loams, and clays are found throughout the valley, and gravel is found in all areas except the central trough.

Periods of high wind blowing through San Gorgonio Pass down the valley are common in the spring and early summer. These winds are responsible for a redistribution of the soils of the valley.

Because of the arid nature of the area, there has been no natural leaching outside of stream channels. Such leaching is responsible, in more humid regions, for a modification of the soil profile. In profile, Coachella Valley soils are extremely stratified, with irregular layers of sands and loams and, usually, clays. These layers are from a fraction of an inch to a foot or so thick. There are sharp, clearly defined planes between the layers.

A soil survey[6] has been made of most of the Coachella Valley area. The difficulties encountered in classifying the soil, in such an area as this, are great. The classification as to soil type appears to be based largely on the nature of the surface soil for the two agriculturally important series. The top soil of the Coachella series has been deposited and reworked principally by wind action, while the Indio series appear characteristically to have been water-deposited. The soils are readily tilled.

There are considerable acreages of two other soils series. The Superstition series is found on the alluvial cones. As a rule it is too coarse and rocky for agricultural use, but some of the finer soils of this type are farmed and appear to be of good quality. The Woodrow series is a heavy soil made up largely out of material settled out in Salton Sea at times when it was a larger body of water. The source of much of its silt is, of course, the Colorado River.

The Storie index[7] has been used to rate the soils of the Coachella Valley.[8] Because of the great amount of stratification found in this area, the general soil ratings cannot always be rigidly applied. Many of the

---

[6] Kocher, A. E., and W. G. Harper. Soil survey of the Coachella Valley area, California. [U. S. Department of Agriculture, Bureau of Soils, in coöperation with the University of California Agricultural Experiment Station.] Government Printing Office, Washington, D. C. 1927.

[7] Storie, R. Earl. An index for rating the agricultural value of soils. California Agr. Exp. Sta. Bul. 556:1–44. 1933. (Out of print.)

[8] Weir, Walter W., and R. Earl Storie. A rating of California soils. California Agr. Exp. Sta. Bul. 599:1–157. 1936. (Out of print.)

Coachella fine sands have a high moisture-holding capacity. Finer soils such as Indio Clay loam, silty phase, are often relatively impervious. These facts can be accounted for in the stratification found—the many abrupt planes separating soils of different texture offering resistance to percolation, and giving light soils high effective "field capacity" and heavy soils poor permeability. This could not be classed as true field capacity since very slow drainage persists, but at slow enough rates so that much of the moisture can be available for plant use.

There are definite trends of the agriculture to shift to lighter soils for practically all crops except cotton. Development of such soils is limited mainly because of leveling costs; they characteristically have a dunelike or hummocked surface. Most of the recent developments have been on soils of the Coachella series.

Development of the Agriculture.—Agriculture began in Coachella Valley about the turn of the century when it became economically feasible to drill deep wells for agricultural purposes. Early developments were in the artesian area. With improvement in pumping equipment, a new impetus was given development. It was then that the trend away from the heavy, often saline, soils found in the artesian area, started. Beginning about 1920 there was a considerable development of cotton plantings on the heavier soils, but most of such plantings have long since been abandoned.

Principal crops in the early days were winter vegetables and spring melons. Melons are seldom grown now. Greatest acreage is still in winter vegetables, but plantings of dates, grapefruit, and grapes have steadily increased. A considerable acreage has been planted to alfalfa on the lighter soils. This crop is also grown on the heavier soils, usually in rotation with cotton. Included in this report is a crop survey made in 1936–37.

SOIL-MOISTURE TECHNIQUE EMPLOYED

Plant-Soil-Water Relations.[9]—The soil is a reservoir of water, which is available in certain definite amounts, to the roots of plants. The amount of moisture a given soil will hold, providing there is no restricted drainage, depends mainly upon the texture of the particles making up the soil and upon the structure of the mass and to a lesser extent upon depth of soil, depth to water table, temperature, and dissolved salts. When gravitational movement of moisture in a soil ceases after irrigation that soil is said to be at *field capacity.* This is expressed as a percentage relation of the moisture present to the dry weight of the soil.

The *permanent wilting percentage* is the moisture content below which plants cannot readily obtain water. If the soil moisture is in the range between field capacity and permanent wilting percentage, plants can readily secure water. The condition may occur, however, wherein only part of the soil contains available moisture and transpirational use will be limited to what the roots in that portion of the soil may obtain.

---

[9] Veihmeyer, F. J., and A. H. Hendrickson. Essentials of Irrigation and cultivation of orchards. California Agr. Ext. Cir. 50:1–24. Revised, 1936. (Out of print.)

The amount of water extracted from the soil by the roots of plants is here called *transpirational use*. Not all the water applied can be accounted for in transpirational use. The losses include water which evaporates from the surface, water which percolates below the root zone, and any water which actually runs off the surface of the plot. *Irrigation efficiency* is the percentage of the water applied that results in moisture increase within the soil zone sampled.

Field experience indicates that the principal direct evaporation occurs in the top 5 inches or so. Under normal practice in the area under consideration this "mulch" is regularly cultivated which prevents any appreciable amount of roots from growing therein. By starting sampling at the bottom of the mulch, the data obtained on moisture extraction closely approximate transpirational use.

Selection of Plots.—In making precise soil-moisture investigations, uniform plots should be established in a uniform soil, and differential treatments should be undertaken. Such procedure was not feasible in this case, nor was it possible to establish any differential treatments. Instead, plots were established in commercial plantings which, as far as could be ascertained, produced good yields of high-quality fruit.

Preliminary work done in 1932 showed that the soils in the region are extremely variable, and this indicated the necessity of using caution in finding locations where reasonably approximate results could be obtained. With the stratified sandy soils of Coachella Valley, it is usual that downward moisture movement does not cease within a few days after irrigation but continues for weeks or even months. Unless extreme caution was exercised soil-moisture investigations would not only be of lesser significance because of soil variabilities, but slow drainage would be mistaken for transpirational use. This latter factor necessitated abandonment of a number of plots, and guarding against excessive irrigations which tended to aggravate the situation in all plots. Despite these precautions, the final analysis of the data have shown that slow seepage undoubtedly existed much of the time in many of the plots—the data for which were discarded.

Essentially, the slow drainage or seepage means that there was no apparent true field capacity. Under the common irrigation practices of Coachella Valley, it is normal that there be almost continuous slow drainage of moisture downward and out of the root zone.

Methods.—When orchard plantings were selected they were carefully looked over for plot location. The plots were located where trees were of uniform size and vigor and were surrounded on all sides by similar trees. Six or more trees were included in the plot, and the irrigation treatment was kept essentially the same as that received by the surrounding trees. Procedure was the same in the vineyard except as to the number of vines included in the plot.

An effort was made to make the plots as level as possible. This made it feasible to distribute the water uniformly over the plots and obtain high irrigation efficiencies.

Levees were built up around the plots after each cultivation and the area measured. The amount of water applied at each irrigation was measured with a weir or a 3-inch Parshall measuring flume, according to the rate of application. For three of the plots permanent weir boxes were constructed.

Moisture content of the soil was determined before and after each irrigation and normally at one intermediate time. These determinations were made by sampling with a soil tube, weighing the samples at field moisture, and then oven-drying at 105° to 110° Centigrade. Each sampling represents an average of ten cores. Except in the case of the grape plots, samples were taken in 2-foot increments to a depth of 8 feet excluding the mulch.

In the date and grape plots, from 1936 to 1939 inclusive, all ten holes for moisture sampling were equally spaced along one diagonal line across the plot. In the grapefruit plots two such diagonal lines were used with 4 to 6 holes in each line. In the grapefruit plots it was, of course, impracticable to sample under the skirt of the tree. At each sampling the diagonal line or lines were moved 1 foot down the row (assuming water entered at the "upper" end). When the end of the plot was reached, the holes were offset and the diagonal line was reversed and moved up the row.

Samples were taken from each plot for moisture equivalent several times during the course of the investigation. The *moisture equivalent* is a measure of the moisture-holding properties of a soil. Essentially, it is the percentage amount of moisture on an over-dry basis which is retained in a given amount of soil which has been subjected under a standardized procedure to a centrifugal force of 1,000 times gravity. For most fine-textured soils the moisture equivalent agrees closely with the field capacity. There should be no appreciable amount of drainage when soil is at or below the moisture equivalent.

Samples were also obtained for determination of the permanent wilting percentage on each plot at each depth.

Each year one or two samplings were made to determine the *apparent* *specific gravity* (sometimes called volume weight) of the soil of each depth in each plot. This is the ratio of the oven-dry weight of a given volume of undisturbed soil to the weight of an equal volume of water. Its determination is necessary to compute the actual quantity of water in the soil from the moisture percentages. Most of these determinations were made with soil tubes, accurately measuring the exact volume of soil in the sample. Where soil-tube measurements were questionable, pits were dug to the top of the zone in question and the soil leveled. Cores of 6-inch diameter and 2-foot depth were then removed for determination of oven-dry weight. The exact volume of the hole was checked by filling with a sand of known apparent specific gravity, and weighing the sand required to fill the hole.

Limitations and Accuracy of Work.—There are certain limitations to the soil-moisture sampling program above outlined which affect the accuracy of the results. These, with their explanations, might be enumerated as follows:

1. The ten sets of samples taken on each sampling date, about the best number for the purpose, did not give precisely the average moisture content of the soil in the entire plot.

2. The ten holes could not be spaced, for any one sampling date, so that each would truly represent a proportionate part of the root zone of any one tree or group of trees.

3. Because of the extreme variability of Coachella Valley soils it would have taken almost an infinite number of samples on each sampling date to get precisely the average soil-moisture content. If many more samples had been taken an appreciable number of roots would have been cut.

4. Because of the irregular stratification in the soil, samples obtained are approximations of *average* moisture conditions and not necessarily indicative of the condition in one particular stratum. In other words, one layer of relatively uniform soil may be dry while another layer in the same sample might still be moist. Only the average moisture in the entire sample was measured.

5. In obtaining each sample for moisture equivalent and permanent wilting percentage a number of distinctly different soils (as represented by each little stratum) were taken and mixed to make a homogeneous mass. The determinations made might be approximations of the averages of the characteristics of all the strata, but not necessarily so.

6. It was frequently found to be impossible to distinguish between drainage and transpirational use. Generally, the criterion herein used to determine whether any appreciable drainage was involved in the soil-moisture data, was whether the zone of 6–8 foot depth was at or below the average moisture equivalent. It would not be expected that any appre-

ciable deep percolation would be taking place under this condition, and inspection of all available data seems to bear this out.

It was recognized that it would be impossible to get any figures for permanent wilting percentages that would apply to the samples taken for moisture determination or indicative of when the trees approached a wilt. Permanent wilting percentages were determined, therefore, merely as an index of the moisture properties of the mixed soil sample. They in no way were used as a basis for adjusting the irrigation practices employed.

As previously stated, it was planned to follow, essentially, the irrigation practices of the owners, and to gauge the adequacy of these treatments by: (1) analyzing the character of the soil-moisture extraction curves obtained, and (2) making growth measurements which would show rate differences within the intervals between irrigations.

Example of Method of Interpreting Data.—Because of its bulk not all the original data can be published. Therefore, only one season's data for plot D–10, in a date orchard, is given in detail, to illustrate typical data secured as well as limitations involved in the records. Table 2 is the record of moisture percentages for that plot for the 1937–38 season. Each figure represents the average for ten separate samples. The records of moisture equivalent, permanent wilting percentage (mixed soil), and apparent specific gravity are as follows:

	0–2 ft. depth	2–4 ft. depth	4–6 ft. depth	6–8 ft. depth
Moisture equivalent, per cent	12.3	10.4	12.0	6.7
Permanent wilting percentage	2.8	2.6	2.4	1.6
Apparent specific gravity	1.20	1.20	1.30	1.44

Moisture percentages were converted to equivalent inches depth of water and the resultant data were charted. To convert table 2: equivalent inches depth $=\frac{\text{moisture per cent}\times 24\times\text{apparent specific gravity}}{100}$. The data of table 2, plotted as equivalent inches depth, are shown in figure 1. Indicated on this same figure are the moisture equivalents and permanent wilting percentages expressed as equivalent inches depth of water.

The 5½-month interval between irrigations shown on this record is not customary. It resulted from the owner's decision to remodel his water-distribution system. Until this interval, moisture in the 6–8 feet depths had always been above the moisture equivalent. It was apparent that drainage as well as transpirational use affected the slopes of the curves prior to October, and therefore these early records have not been included as transpirational use.

Irrigation efficiency, which represents the approximate proportion of

TABLE 2

AVERAGE SOIL MOISTURE FOR EACH SAMPLING OF DATE PLOT D–10*

Date sampled, 1937-38	Moisture at the given sampling depths, as per cent of dry weight			
	0–2 feet	2–4 feet	4–6 feet	6–8 feet
April 19, 1937	25.9	21.5	20.6	10.8
April 26	18.4	17.1	....	....
May 3	20.9	15.3	18.2	10.0
Irrigated May 4, 1937; 8.6 inches water				
May 8	26.9	22.0	21.8	10.4
May 17	21.0	19.1	....	....
May 24	21.5	16.7	18.2	10.0
Irrigated May 24; 6.7 inches water				
May 28	27.3	21.6	20.2	9.9
June 7	22.6	19.6	....	...
June 12	21.9	16.8	18.1	9.6
Irrigated June 12; 7.4 inches water				
June 16	28.2	22.4	22.0	9.7
June 25	22.8	18.1	....	...
June 30	18.4	16.2	16.9	9.4
Irrigated June 30; 8.4 inches water				
July 5	25.0	21.7	19.0	9.9
July 12	21.8	18.8	....	...
July 21	17.5	17.5	15.4	8.8
Irrigated July 22; 8.0 inches water				
July 27	24.4	21.0	18.1	8.7
August 6	22.1	18.6	....	...
August 11	19.4	17.9	15.5	8.3
Irrigated August 11; 8.2 inches water				
August 16	23.3	23.6	18.7	8.1
August 21	21.7	21.8	....	...
September 8	18.1	15.5	15.1	7.3
Irrigated September 8; 7.9 inches water				
September 14	22.1	21.7	19.3	7.3
September 20	20.5	22.1	....	...
October 7	19.3	18.0	15.1	7.2
December 7	15.7	11.6	10.0	5.5
January 18, 1938	14.7	10.1	7.6	4.7
February 25	12.4	8.4	6.8	4.4
Irrigated February 25, 7.2 inches water, and rain, March 2, 1.4 inches				
March 4	24.5	17.7	7.7	3.9
March 12	20.8	19.3	...	...
March 25	17.1	17.3	9.6	3.9

* Soil-moisture determinations based on ten samples.

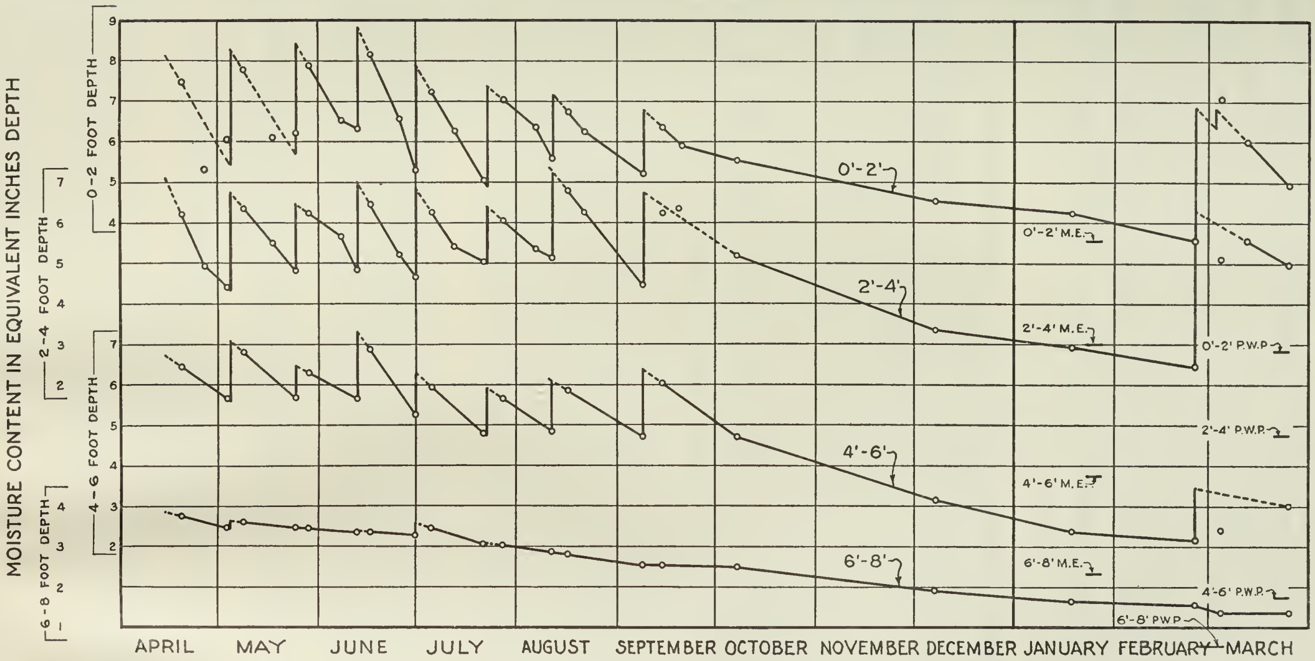

Fig. 1.—Soil-moisture chart of date plot D–10, for the 1937–38 season, showing average moisture content of the soil in each depth zone on each sampling day, and curves used in computing rate of moisture loss. The vertical lines indicate moisture increase because of irrigations or rain. Lines are dotted where the rate of moisture loss is assumed from inadequate or conflicting data. Actual moisture percentages have been converted to equivalent inches depth of water in this chart. Average moisture equivalents (M.E.) and average permanent wilting percentages (P.W.P.) are also converted and their value for each depth is indicated.

the water applied which is evidenced in soil-moisture increase, was computed from charts such as figure 1. Soil-moisture increases, as represented by the vertical lines, were totaled. Depths of the irrigations applied were likewise totaled. At the end of each season the average efficiency was computed. Because of the soil variability, efficiencies obtained for single irrigations were variable and were not computed.

Transpirational use of water was next tabulated. Table 3 shows these data, prepared from a chart similar to figure 1. Moisture loss is totaled at the bottom of the table. The percentage of the total for each depth zone is assumed to represent the root distribution. Total loss per period is converted to the equivalent rate per 30 days, as shown on the right of the table.

TABLE 3

LOSS OF WATER BY TRANSPIRATION IN INTERVALS BETWEEN IRRIGATIONS; DATE PLOT D–10

Intervals	Days	Equivalent inches depth at the given sampling depths				Total	Equivalent in 30 days
		0–2 feet	2–4 feet	4–6 feet	6–8 feet		
1937							
March 26 to September 30*	..	....	....	....	....	....	...
September 30 to October 31	31	0.55	1.12	1.02	0.25	2.94	2.8
October 31 to November 30	30	0.50	0.93	0.78	0.29	2.50	2.5
November 30 to December 31	31	0.29	0.43	0.36	0.23	1.31	1.3
1937-38							
December 31 to January 31	31	0.35	0.34	0.40	0.15	1.24	1.2
January 31 to February 25	25	0.43	0.32	0.15	0.05	0.95	1.1
February 25 to March 25	28	2.34	0.15	0.27	0.17	2.93	3.1
Total	...	4.46	3.29	2.98	1.14	11.87	...
Per cent lost at each depth	...	37	28	25	10	.....	...

* Data not included because of continued drainage.

The next step was to chart the rates of transpirational use (loss) of water for the periods indicated, and convert to calendar months.

RESULTS OF SOIL-MOISTURE INVESTIGATIONS IN DATE ORCHARDS

Description of the Date Plots.—Plot D–1: This plot is located 1½ miles west of Indio. It was planted in 1927 or earlier with the palms spaced 30 × 30 feet. The ground is cultivated four to eight times a year, so there are normally very few weeds. The planting is fertilized annually. The palms are somewhat tall for their age, indicating vigorous growth. The manager reported that quality and yields were probably slightly better than the average for the valley. The plot was abandoned in August, 1936, because a condition of severely restricted drainage became evident.

Plot D–2: This plot is located 2 miles west of Indio. The palms were planted between 1921 and 1923 with the spacing 30 × 30 feet. It is cultivated a maximum of four times a year, and the covercrop is normally heavy before each cultivation. The planting is regularly fertilized. A typical practice was the application of 8 tons per acre of manure applied in December, 1937, with a covercrop being planted the following January.

Difficulty was experienced, in D–2, in applying sufficient water to obtain adequate penetration. When work was started on the plot the soil was moist only to a depth of 2 feet but, except for several periods noted, available moisture was maintained at all depths.

In 1938 the yield of the 41 bearing palms in the planting averaged 157 pounds per tree. No other yield records were obtained, but yields for 1937 and 1938 were considered to have been lowered by the freeze of January, 1937. When the plot was started the owner stated he had been somewhat dissatisfied with yield and quality for several years.

Plot D–9: This plot is located just north of the highway in the Indian Wells district. The trees were planted in 1929 with the usual spacing of 30 × 30 feet. Cultivations are normally as frequent as eight per year, and there is never any appreciable weed growth. One covercrop was planted during the life of the plot (January, 1938). The normal fertilization program calls for 15 pounds ammonium sulfate per tree and 5 tons manure per acre applied each January. The irrigation water contains some nitrogen.

The yield and quality of fruit from the planting had been exceptionally good prior to establishing the plot. However, the trees were severely injured by the freeze of January, 1937. That year eight bunches were allowed to remain on each tree and 115 pounds of fruit per bearing palm was harvested (12 per cent grade B, 40 per cent grades C and D, 8 per cent culls). As a result, in 1938 only 3 trees bore fruit, there being a total of seven fruit bunches.

Plot D–10: This plot is in the same planting as plot D–1, but the palms were set out in 1930. The only significant differences were the younger palms, a lighter and more uniform soil, and the growing of one covercrop in an otherwise clean-cultivated orchard. This covercrop was planted on February 25, 1938, and became high and exceptionally dense before being turned under on July 7.

Yields were affected in both 1937 and 1938 by the freeze. In 1938 there were 134 bunches on the 14 trees, with an average of 92 pounds per tree.

TABLE 4

MOISTURE EQUIVALENT, PERMANENT WILTING PERCENTAGE, AND APPARENT SPECIFIC GRAVITY FOR THE SOILS OF THE DATE PLOTS, AT VARIOUS DEPTHS*

Soil characteristics	0–2 foot depths	2–4 foot depths	4–6 foot depths	6–8 foot depths
Plot D-1; Indio loam				
Range of moisture equivalent, per cent	11.2–11.4	8.5–9.3	38.5–39.1	38.4–38.9
Average moisture equivalent, per cent	11.3	9.0	38.7	38.6
Permanent wilting percentage	2.7	2.5	11.0	8.1
Apparent specific gravity	1.18	1.20	1.01	1.06
Plot D-2; Indio very fine sandy loam				
Range of moisture equivalent, per cent	19.7–21.4	9.4–22.2	12.2–34.4	12.1–21.2
Average moisture equivalent, per cent	20.6	17.2	23.7	17.2
Permanent wilting percentage	6.1	3.0	10.7	5.3
Apparent specific gravity:				
April, 1936 to March, 1937	1.06	1.18	1.12	1.42
April, 1937 to March, 1938	1.11	1.16	1.16	1.43
April, 1938 to March, 1939	1.09	1.16	1.16	1.43
Plot D-9; Coachella fine sand				
Range of moisture equivalent, per cent	9.8–12.9	14.3–22.0	11.5–13.3	5.1–12.2
Average moisture equivalent, per cent	11.4	17.3	12.1	8.7
Permanent wilting percentage	3.5	5.2	3.6	2.0
Apparent specific gravity:				
1936 to March, 1937	1.06	0.98	1.16	1.29
April, 1937 to March, 1938	1.22	1.13	1.20	1.25
April, 1938 to March, 1939	1.22	1.14	1.18	1.21
Plot D-10; Coachella fine sand				
Range of moisture equivalent, per cent	9.4–13.9	8.3–12.2	7.6–18.7	4.9–9.0
Average moisture equivalent, per cent	12.3	10.4	12.0	6.7
Permanent wilting percentage	2.8	2.6	2.4	1.6
Apparent specific gravity:				
1936 to March, 1937	1.12	1.14	1.28	1.40
April, 1937 to March, 1938	1.20	1.20	1.30	1.44
April, 1938 to March, 1939	1.20	1.20	1.21	1.38
Plot CD-2; Indio very fine sandy loam				
Range of moisture equivalent, per cent	16.3–21.0	12.6–13.6	5.2–15.0	6.3–18.2
Average moisture equivalent, per cent	18.2	13.2	10.0	11.4
Apparent specific gravity:				
February, 1937 to March, 1938	1.17	1.26	1.45	1.54
April, 1938, to March, 1939	1.18	1.26	1.44	1.61

* Only one set of permanent wilting percentage samples was obtained from each plot, and none in plot CD-2; the data for plot CD-2, however, should approximate those for soils with similar moisture equivalents. The range for moisture equivalent is based on four or more samples.

TABLE 5

TRANSPIRATIONAL SOIL-MOISTURE LOSSES IN EQUIVALENT INCHES DEPTH IN DATE PLOTS FOR PERIODS WHEN NO APPRECIABLE AMOUNT OF DRAINAGE WAS POSSIBLE AND PER CENT LOSS AT EACH DEPTH FOR THE TOTAL PLOT RECORD*

Interval of record	Equivalent inches loss at the given depths				Total	30-day equivalent†
	0–2 feet	2–4 feet	4–6 feet	6–8 feet		
Plot D–B						
1932						
May 5 to May 16	3.08	0.12	0.00	0.00	3.20	8.8
August 1 to August 9	2.40	0.17	0.00	0.00	2.57	9.7
Per cent loss at each depth	95	5	0	0	....	....
Plot D-C						
1932						
June 6 to June 20	0.88	3.01	1.29	0.15	5.33	11.4
Per cent loss at each depth	17	56	24	3	....	....
Plot D-M						
1932						
July 2 to July 11	1.87	0.32	0.00	0.00	2.19	7.3
August 15 to August 24	1.68	0.27	0.00	0.00	1.95	6.5
November 4 to December 5	2.57	1.22	0.00	0.00	3.79	3.7
Per cent loss at each depth	77	23	0	0	....	....
Plot D-N						
1932						
October 14 to December 6	2.63	3.03	1.22	0.00	6.88	3.9
Per cent loss at each depth	38	44	18	0	....	...
Plot D-1						
1936						
March 30 to April 15	2.44	2.04	0.00	0.00	4.48	8.4
Per cent loss at each depth	55	45	0	0	....	...
Plot D-9						
1936						
August 31 to September 14	2.60	0.75	0.82	0.29	4.46	9.6
September 14 to September 28	2.08	0.67	0.12	0.11	2.98	6.4
September 28 to October 13	2.38	0.39	0.00	0.00	2.77	4.0
October 19 to November 10	2.26	0.45	0.13	0.00	2.84	3.9
Per cent loss at each depth	71	17	9	3	....	...

(Continued on next page.)

* Records for losses are included when the 6–8 foot depth is near to or below the moisture equivalent.

† Equivalent total loss in inches depth for a 30-day period.

TABLE 5—(*Continued*)

Interval of record	Equivalent inches loss at the given depths				Total	30-day equivalent†
	0–2 feet	2–4 feet	4–6 feet	6–8 feet		
			Plot D-10			
1936						
October 9 to November 6	2.05	1.52	0.35	0.28	4.20	4.5
November 6 to January 26	2.66	2.36	2.10	0.32	7.44	2.8
1937						
January 26 to February 6	0.67	0.79	0.25	0.00	1.71	4.7
February 6 to February 27	1.38	1.47	0.62	0.00	3.47	5.0
February 27 to March 26	2.29	2.13	0.50	0.16	5.08	5.6
September 30 to October 31	0.55	1.12	1.02	0.25	2.94	2.8
October 31 to November 30	0.50	0.93	0.78	0.29	2.50	2.5
November 30 to December 31	0.29	0.43	0.36	0.23	1.31	1.3
December 31 to January 31	0.35	0.34	0.40	0.15	1.24	1.2
1938						
January 31 to February 25	0.43	0.32	0.15	0.05	0.95	1.1
February 25 to March 25	2.34	0.15	0.27	0.17	2.93	3.1
March 25 to April 13	2.40	1.09	0.00	0.00	3.49	5.5
April 13 to April 28	2.48	1.21	0.00	0.00	3.69	7.4
April 28 to May 12	3.58	2.46	0.38	0.00	6.42	13.8
Per cent loss at each depth	46	35	15	4	....	....
			Plot D-2			
1936						
April 13 to April 30	2.16	0.00	0.00	0.00	2.16	3.8
April 30 to May 22	4.66	1.98	0.33	0.00	6.97	9.5
May 22 to June 12	4.42	0.63	0.98	0.10	6.13	8.8
June 12 to June 29	3.80	0.19	0.00	0.06	4.05	7.1
June 29 to July 16	3.30	0.12	0.23	0.00	3.65	6.4
July 16 to August 7	5.01	1.36	0.30	0.00	6.67	9.1
August 7 to August 24	3.36	1.80	0.18	0.00	5.34	9.4
August 24 to September 10	2.70	0.34	0.00	0.00	3.04	5.4
1937						
May 25 to June 14	3.30	1.21	0.39	0.00	4.90	7.4
June 14 to July 5	3.69	1.55	0.42	0.68	6.34	9.1
July 5 to July 26	3.20	2.22	0.25	0.69	6.36	9.1
July 26 to August 16	5.05	1.29	1.61	0.00	7.95	11.4
August 16 to September 3	4.50	1.39	0.80	0.42	7.11	11.9
September 3 to September 30	5.08	1.64	0.75	0.37	7.84	8.7
September 30 to October 27	4.16	2.04	0.58	0.27	7.05	7.8
October 27 to December 3	3.60	0.77	0.86	0.37	5.60	4.5
December 3 to December 28	1.46	0.83	0.07	0.00	2.36	2.8
December 28 to January 28	3.41	1.03	1.04	0.18	5.66	5.5

* Records for losses are included when the 6–8 foot depth is near to or below the moisture equivalent.
† Equivalent total loss in inches depth for a 30-day period.

TABLE 5—(*Concluded*)

Interval of record	Equivalent inches loss at the given depths				Total	30-day equivalent†
	0–2 feet	2–4 feet	4–6 feet	6–8 feet		
Plot D-2—*Continued*						
1938						
January 28 to February 26	3.00	0.66	0.00	0.28	3.94	4.1
February 26 to March 24	3.64	1.34	0.00	0.00	4.98	5.7
March 24 to April 22	3.70	2.02	0.00	0.66	6.38	6.6
April 22 to May 21	3.04	2.10	0.11	0.67	5.92	6.1
May 21 to June 14	3.58	2.02	0.48	0.37	6.45	8.1
June 14 to June 30	4.06	0.55	0.00	0.06	4.67	8.8
June 30 to July 22	4.43	3.08	0.25	0.78	8.54	11.6
July 22 to August 9	3.93	1.86	0.52	0.00	6.31	10.5
August 9 to August 30	3.70	3.17	1.93	0.00	8.80	12.6
September 23 to November 1	3.63	2.50	1.54	0.55	8.22	6.3
November 1 to December 1	1.13	1.28	0.74	0.41	3.56	3.6
December 1 to January 18	0.86	0.43	0.27	0.63	2.19	1.4
1939						
January 18 to February 16	1.30	0.00	0.00	0.00	1.30	1.3
Per cent loss at each depth	63	24	9	4	....	....
Plot CD-2						
1937						
February 2 to February 17	1.46	0.00	0.00	0.00	1.46	2.9
February 17 to March 10	1.98	0.00	0.00	0.00	1.98	2.8
March 10 to April 7	2.37	0.00	0.13	0.58	3.08	3.3
April 7 to April 29	1.84	0.66	0.00	0.00	2.50	3.4
April 29 to May 21	3.81	1.12	0.00	0.38	5.31	7.2
May 21 to June 9	3.83	0.56	0.00	0.10	4.49	7.1
June 9 to June 26	4.00	0.86	0.10	0.00	4.96	8.8
June 26 to July 13	3.66	0.80	0.00	0.07	4.53	8.0
July 13 to July 29	2.82	0.13	0.16	0.00	3.11	5.8
October 18 to November 24	4.03	0.85	0.63	0.20	5.71	4.6
November 24 to December 15	0.59	0.42	0.36	0.09	1.46	2.1
December 15 to January 14	2.36	0.95	0.17	0.00	3.48	3.5
1938						
January 14 to February 17	2.50	1.08	0.60	0.11	4.29	3.8
February 17 to March 18	3.51	0.86	0.00	0.07	4.44	4.6
March 18 to April 15	3.27	1.17	0.41	0.20	5.05	5.4
April 15 to May 16	5.26	1.88	0.74	0.51	8.39	8.1
May 16 to June 3	2.84	0.70	0.13	0.41	4.08	6.8
June 3 to June 17	2.74	0.89	0.25	0.28	4.16	8.9
June 17 to July 1	2.12	1.00	0.00	0.00	3.12	6.7
July 1 to July 21	4.99	1.40	0.26	0.85	7.50	11.2
July 21 to August 18	5.40	1.89	0.14	0.47	7.90	8.5
August 18 to September 14	6.39	1.42	0.31	0.21	8.33	9.2
September 14 to October 7	5.34	1.75	0.71	0.26	8.06	10.5
October 7 to November 4	4.14	1.12	0.17	0.33	5.76	6.2
November 4 to December 15	2.56	0.25	0.26	0.16	3.23	2.4
December 15 to January 25	1.49	0.56	0.00	0.10	2.15	1.6
1939						
January 25 to February 23	2.20	0.71	0.17	0.32	3.40	3.5
Per cent loss at each depth	72	19	5	4	....	....

---

* Records for losses are included when the 6–8 foot depth is near to or below the moisture equivalent.

† Equivalent total loss in inches depth for a 30-day period.

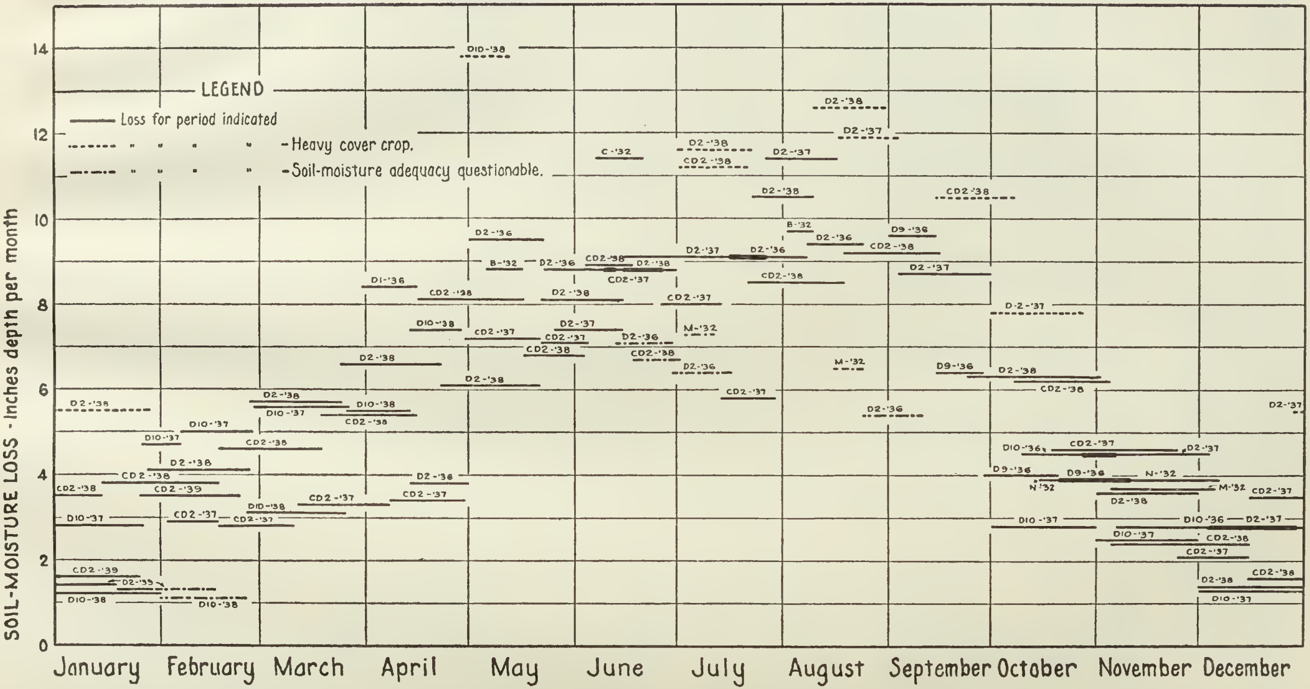

Fig. 2.—Showing records for all transpirational use of water in Coachella Valley date plots where the 6–8 foot depth was near or below the moisture equivalent—indicating little or no downward movement of moisture. Length of horizontal line indicates the period of record (usually the interval between irrigations). Notation refers to plot and year. Horizontal lines are widened where they overlap.

Plot CD–2: This date orchard with grapefruit interplanted is located west of Coachella. The dates were planted before 1920. The grapefruit trees, which were planted in 1932, in the shade of the palms, have grown very slowly. The dates are planted on 30-foot centers with a grapefruit tree in each middle between four palms. There are 3 to 4 cultivations per year. A covercrop is grown each spring. Both organic and commercial fertilizers are applied annually.

Difficulty was always experienced on plot CD–2 in securing uniform distribution of the water and in obtaining adequate penetration. The soil was moist only to a depth of 2 feet when work was started on the plot.

In 1938 the date yield was 225 pounds of fruit per tree (there were 12 trees). The 1937 crop had been heavily thinned because of the freeze. The grapefruit trees do not produce very good yields, but quality is good.

TABLE 6

Percentage of Water Applied Accounted for in Soil-Moisture Increase in the Date Plots

Plot no.	1936–37	1937–38	1938–39	Average
D-1	82	..	..	82
D-2	78	78	82	79
D-9	50*	90†	84	77
D-10	78	77	92	84
CD-2	..	96‡	86‡	90‡

* Most of the sampling was at the high end of the plot where the soil received less than the average depth of water.

† Most of the sampling was at the low end of the plot.

‡ Could not get even distribution of water over the long narrow plot.

Soil Characteristics of the Date Plots.—The principal soil characteristics of the date plots are shown in table 4. Permanent wilting percentage samples were obtained only once at each plot, but moisture equivalent samples were obtained at least once a year. Because of the great variation of moisture equivalent values obtained from the different samples, range, as well as average moisture equivalent is shown. The soil in any of the plots never reached the permanent wilting percentage found for the mixed soil; the closest approach was made in plot D–10 in the winter of 1937–38. (See fig. 1.)

Plot D–9 took water most readily and plots D–2 and CD–2 least readily. In a test run, June 12, 1936, on plot D–2, water was percolating into the soil at a rate of 1.6 inches per hour after 1 hour, 1.2 inches after 2 hours, and 0.7 inch after 5 hours. This was the first irrigation after cultivation, and rates were unusually high. With both plots D–2 and CD–2, it was frequently necessary to apply water two days in succession to obtain penetration to an adequate depth.

Transpirational Use.—All records of transpirational use by plots, where no probability of appreciable restricted drainage existed, are given in table 5. Included are the records for some similar preliminary plots sampled in 1932. These data are summarized in figure 2. Some of the low records are shown with broken lines. For these there were indications that growth of the palm was slightly inhibited during the interval. Some high records are dotted. During these intervals vigorous cover-crops, either planted or volunteer, were growing on the plots.

TABLE 7

TRANSPIRATIONAL USE OF WATER AND ADJUSTED AMOUNTS OF WATER APPLIED ON DATE PLOTS, EXPRESSED AS EQUIVALENT INCHES DEPTH

Month	Transpirational use*			Adjusted amounts of water average of all plots
	Average of all plots	Plot D-2	Plot CD-2	
January	2.9	3.4	2.8	3.6
February	3.4	3.2	3.5	4.2
March	4.6	5.9	4.0	5.8
April	6.2	6.5	5.1	7.8
May	7.9	8.2	7.3	9.9
June	8.3	8.5	8.0	10.4
July	9.1	10.1	8.5	11.4
August	10.0	10.7	8.8	12.5
September	8.6	7.9	9.9	10.8
October	5.4	6.8	6.4	6.8
November	3.6	4.1	3.5	4.5
December	2.4	2.2	2.4	3.0
Total	72.4	77.5	70.2	90.7

* Taken from figure 2.

Irrigation Efficiency.—By measuring the amount of water applied to the plots, and determining the soil-mixture increases, it was possible to determine the approximate percentage of water applied which was actually used by the plants. Table 6 lists the average efficiencies found for each plot for each season.

Because water could not be applied evenly on the entire plot, efficiency data for plot CD–2 are apparently high and not utilized.

Weighting the averages for each plot by length of record, but excluding plot CD–2, an average irrigation efficiency of 80 per cent was obtained.

Water Applied.—By dividing the average transpirational use for each plot by the average efficiencies obtained (divided by 100) the "adjusted amounts of water applied" were calculated. Transpirational use for two typical plots, and average transpirational use and water applied on all plots are shown in table 7. Essentially, the latter figures are the actual amounts of water applied per year adjusted by months to be proportional to the transpirational use.

Root Distribution.—Root distribution, as evidenced by the relative rates at which moisture is extracted from the several depth zones,[10] is shown in table 8. These data show root activity down to a depth of 8 feet below the mulch. There may be roots below that depth and some moisture may be extracted by them. However, from preliminary work done in 1932 it was concluded that any amounts concerned were too small to appreciably affect the data.

TABLE 8

PERCENTAGE OF TOTAL TRANSPIRATIONAL USE IN DATE PLOTS BY DEPTH, INDICATING ROOT DISTRIBUTION

Plot number and year	0–2 feet	2–4 feet	4–6 feet	6–8 feet
DB (1932)	95	5	0	0
DC (1932)	17	56	24	3
DM (1932)	77	23	0	0
DN (1932)	38	44	18	0
D-1 (1936)	55	45	0	0
D-2 (1936–39)	63	24	9	4
D-9 (1936–39)	71	17	9	3
D-10 (1936–39)	46	35	15	4
CD-2 (1937–39)	72	19	5	4
Average	59	30	9	2

Growth Rates.—Plant growth and productivity constitute the basic index of the adequacy of soil moisture. This project was not of long enough duration, nor were the plots under rigid enough control to obtain any correlation between crop and soil-moisture conditions.

Periodic measurement of the growth of new leaves at the tops of the palms was selected as the most promising method of detecting any immediate response of the plants to soil-moisture increase. Palm leaves appear to elongate from the basal end at a uniform rate, provided that environmental conditions remain the same. During that growth period they are erect, several leaves being bunched together. Growth decreases or stops entirely by the time they start to bend over towards the horizontal. Mason,[11] at Indio, and others have made leaf-growth measurements for correlation with temperature and sunlight, but no record could be found of experiments utilizing such measurements for noting responses to soil moisture. An arbitrary standard procedure was therefore adopted which it was hoped would give sufficient data.[12, 13] Moore and Aldrich[14] have since adopted a similar method.

---

[10] Conrad, John P., and F. J. Veihmeyer. Root development and soil moisture. Hilgardia 4(4):113–34. 1929.

[11] Mason, Silas C. The minimum temperature for growth of the date palm and the absence of a resting period. Partial thermostasy of the growth center of the date palm. The inhibitive effect of direct sunlight on the growth of the date palm. Jour. Agr. Res. 31:401–68. 1925.

A fine flexible wire was attached to one of the new small center leaves, and that wire was run down the trunk of the palm through screw eyes. The wire was held fairly taut by attaching a small weight to the end. Periodically the distance between a fixed datum point on the trunk and the weight on the end of the wire was measured. The difference between any two readings gave the growth for the period involved. Growth was measured for one leaf on each of four trees in each plot, and averaged. All growth records were converted to average rate in feet per day for each period between measurements. Growth-rate charts for the only two plots where anything approaching dry-soil conditions normally existed are shown in figures 3 and 4.

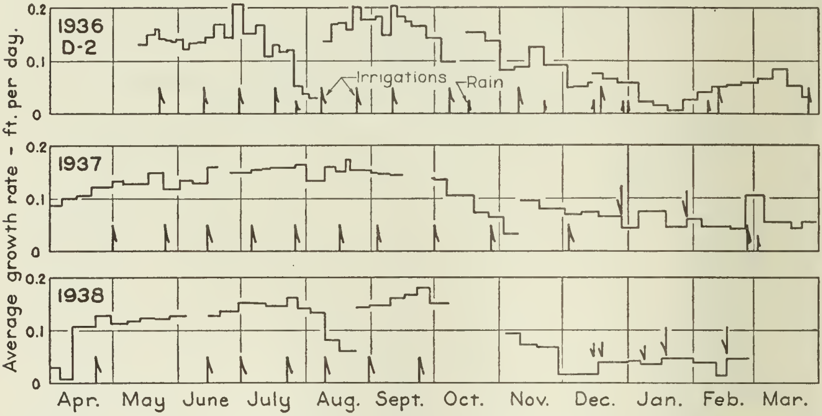

Fig. 3.—Average leaf growth rate for date plot D–2, based on one leaf from each of four trees. As leaves reached maturity, growth ceased or decreased. Changes of leaves so necessitated are shown by breaks in the curves. Arrows indicate rains or irrigations.

Two changes were made in the method of measuring leaf growth during the progress of the investigations. In 1936 linen fish line was used instead of wire. It was found that its length was affected by moisture, so copper wire was substituted in December, 1936. Also, in 1936, measurements were made on the same day at all plots. This method sometimes

---

[12] Pillsbury, Arthur F. How much water does a date palm use? Report of 14th Ann. Date Growers' Inst., Coachella, Calif. April, 1937.

[13] Pillsbury, Arthur F. A further report on water use by Coachella Valley date palms. Report of 15th Ann. Date Growers' Inst. Coachella Valley, Calif. April, 1938.

[14] Moore, D. C., and W. W. Aldrich. Leaf and fruit growth of the date in relation to moisture in a saline soil. Amer. Soc. Hort. Sci. 36:216. 1938.

made it possible to detect variations in growth rates caused by climatic conditions which might otherwise be confused with variations caused by other factors in a particular plot. After 1936 the measurements were made on the same day the plots were sampled.

In 1936 it had been the rule to make all measurements between 6 and 8 a.m. Mason,[15] however, concluded that growth ceased under direct sunlight so it was decided to make the measurements thereafter at any convenient time during the late forenoon or early afternoon. To verify the accuracy of this procedure a recording apparatus was installed to measure leaf growth continuously on a Deglet Noor palm. This record runs from October 31, 1936, to June 8, 1937. These data confirm Mason's findings that there is normally no appreciable apparent growth during the day, even on cloudy days. With the method of measurement employed there was sometimes a slight apparent shrinkage in the morning.

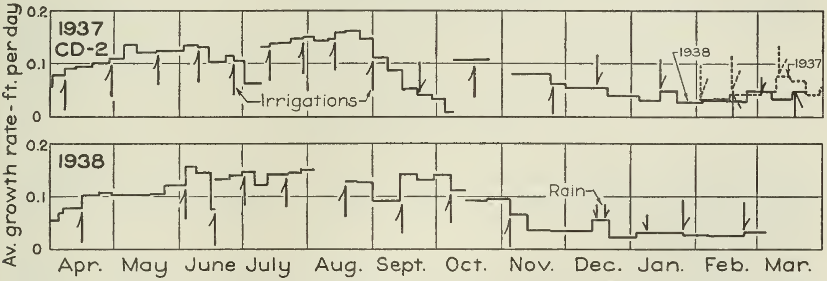

Fig. 4.—Average leaf growth rate for date-grapefruit plot CD–2, based on one leaf from each of four trees. As leaves reached maturity, growth ceased or decreased. Changes of leaves so necessitated are shown by breaks in the curve. Arrows indicate rains or irrigations. In the upper panel the period for February and March, 1937, is indicated by a dash curve.

The growth rates measured for all plots, including those with excessive moisture in parts of the root zone, were similar. There was variation, however, in the rates for individual leaves, and growth became slower shortly before the leaves reached maturity. The objective was simply to relate any growth rate changes to soil-moisture condition.

Inspection of figure 3 shows five appreciable growth-rate increases following irrigation. These occurred June to September, 1936, and in February, 1939. During these periods soil moisture was relatively low in plot D–2, but did not approach the average permanent wilting percentage for mixed soil. Transpirational use was also low. Under the circumstances, the adequacy of soil moisture for full plant growth during part of these intervals may be questioned.

A similar growth response was shown for plot D–10 in February, 1938. Otherwise, all growth records indicated no response to soil moisture.

---

[15] See footnote 11.

RESULTS OF SOIL-MOISTURE INVESTIGATIONS IN GRAPEFRUIT ORCHARDS

Description of the Grapefruit Plots.—Plot C–1: This plot is located 3½ miles southwest of Indio. The trees were planted in March, 1923, spaced 24½ × 24½ feet. It is cultivated only two to three times a year, and weed growth is rank before each cultivation. Covercrops are planted each winter. In 1938 the owner applied 2 pounds of ammonium sulfate per tree and 4 tons of manure per acre. This is a typical annual application, but the grower states he used greater amounts before grapefruit prices declined.

TABLE 9

Moisture Equivalent, Permanent Wilting Percentage, and Apparent Specific Gravity for the Soils of Two Grapefruit Plots, at Various Depths*

Soil characteristics	0–2 foot depth	2–4 foot depth	4–6 foot depth	6–8 foot depth
Plot C-1; Coachella fine sand				
Range of moisture equivalent, per cent	5.7–7.7	12.5–21.6	3.5–7.7	5.2–11.2
Average moisture equivalent, per cent	7.0	17.8	5.9	7.4
Permanent wilting percentage	2.4	6.0	2.1	1.9
Apparent specific gravity:				
April, 1936–March, 1937	1.17	1.14	1.47	1.65
April, 1937–March, 1938	1.31	1.24	1.47	1.49
April, 1938–March, 1939	1.27	1.26	1.54	1.53
Plot C-2; Indio very fine sandy loam				
Range of moisture equivalent, per cent	9.0–12.8	7.6–11.6	6.9–7.9	12.7–15.4
Average moisture equivalent, per cent	10.7	9.6	7.4	13.9
Permanent wilting percentage	2.3	3.6	1.9	3.1
Apparent specific gravity	1.18	1.33	1.44	1.46

* Obtained only one set of permanent wilting percentage samples for each plot. The range for moisture equivalent is based on three or four samples.

The trees are large and vigorous. No yield records could be obtained, but judging from frequent inspection of the orchard, both yield and quality were consistently above average for the Valley.

Plot C–2: This plot is located 2 miles west of Indio. The trees were planted in March, 1924, and are spaced 25 × 24 feet apart. The orchard is cultivated three or four times a year, whenever weeds get too high. Fertilizer is applied annually.

The trees appeared somewhat small for their age, and yields appeared to be about in proportion to tree size. Fruit quality was good. No yield records were obtained.

Adequate penetration of soil moisture was obtained with difficulty. The soil was very hard when dry. In hot summer weather the trees almost always looked wilted at midday regardless of the soil-moisture condition. This was frequently observed in other orchards planted on the Indio loams. The plot was discontinued after one year.

TABLE 10

TRANSPIRATIONAL SOIL-MOISTURE LOSSES IN EQUIVALENT INCHES DEPTH IN GRAPEFRUIT PLOTS FOR PERIODS WHEN NO APPRECIABLE AMOUNT OF DRAINAGE WAS POSSIBLE, AND PER CENT LOSS AT EACH DEPTH FOR THE TOTAL PLOT RECORD

Interval of record	Equivalent inches loss at the given depths				Total	30-day equivalent*
	0–2 feet	2–4 feet	4–6 feet	6–8 feet		
Plot C-1						
1938						
October 8 to November 8	1.76	2.32	0.70	....†	4.78	4.6
November 8 to January 14	2.74	0.47	0.16	....†	3.37	1.5
1939						
January 14 to March 8	1.65	2.02	1.07	....†	4.74	2.7
Total	6.15	4.81	1.93	....	12.89	..
Per cent loss at each depth	48	37	15	....	....	...
Plot C-2 (Irrigation efficiency 80 per cent)						
1936						
September 15 to October 8	2.24	1.37	0.08	....†	3.69	4.8
October 8 to November 13	2.50	0.42	0.08	0.09	3.09	2.6
November 13 to January 20	2.07	0.32	0.31	0.00	2.70	1.2
Total	6.81	2.11	0.47	0.09	9.8	...
Per cent loss at each depth	72	22	5	1	....	...

* Equivalent total loss in a 30-day period.
† Evidence of slow downward moisture movement; assume use is zero.

Soil Characteristics of the Grapefruit Plots.—The principal soil characteristics of the grapefruit plots are shown in table 9. These determinations were made in a manner similar to those shown for the date plots, and the same limitations hold.

Water Use and Root Distribution.—Soil-moisture work was conducted for three years on two grapefruit plots and for one year on one. However, for almost all records slow drainage was in evidence. Table 10 shows such of the transpirational use data as could be reasonably freed from drainage influence. In most of these periods there was evidence of seepage from the 6–8 foot zone, but moisture in the 4–6 foot zone was below the moisture equivalent. Assuming the use of water from the 6–8 foot zone to be negligible, it is possible to compute the use for the top 6 feet.

These records are too few to give any indication of use per year. However, with average applications of 5 to 7 feet in depth per year (varying somewhat with the size of the trees) there was considerable continuous downward movement and no indication at any time that fruit growth was inhibited. It can only be presumed that the net requirements for water application are something less than 5 to 7 feet in depth per year.

Table 10 also gives some data on moisture loss by depth. This would indicate root distribution to be about 50 to 70 per cent in the first 2 feet of depth, and about 85 to 95 per cent in the first 4 feet. This compares closely with citrus root distribution in the south coastal basin of southern California.[16]

Growth Rates.—As early as, or earlier than, 1914, citrus growers measured fruit growth for indications of inadequate soil moisture. Jensen[17, 18] published data on the method in 1918, and since 1931 it has been used by many investigators[19, 20] of the irrigation requirements of citrus crops. Methods used in Coachella Valley were patterned after those used since 1931 by Halma and Beckett in the irrigation orchard at the Citrus Experiment Station, Riverside, which in turn were patterned after methods used elsewhere for deciduous fruits. Circumference was measured, the work being simplified by use of the "circumeter,"[21] developed for this project.

In each plot 10 fruits were tagged on the north side of each of 4 trees. Circumference, to the nearest millimeter, of each tagged fruit was measured periodically shortly after sunrise. Midsummer tests run from sunrise to noon indicated the fruit apparently shrank at a fairly uniform rate through this interval, change in circumference of 1 millimeter taking

---

[16] Unpublished manuscript of the late S. H. Beckett, Citrus Experiment Station, Riverside.

[17] Jensen, C. A. Relation of soil moisture to orange growth. California Citrog. 3(5):98, 113. March, 1918.

[18] Jensen, C. A. Some relations between citrus fruit growth and soil moisture and climatic conditions. Nos. 1 and 2. California Citrog. 4(5):119, 131, March, 1919; 4(7):184, 189, May, 1919.

[19] Halma, F. F. Some phases in the water relation of citrus. Proc. Amer. Soc. Hort. Sci. 31:108–9. 1934.

[20] Taylor, C. A. Use of soil-moisture and fruit growth records for checking irrigation practices in citrus orchards. U. S. Dept. Agr. Cir. 426:1–24. May, 1937.

[21] Pillsbury, A. F., and O. C. Compton. A fruit circumeter. California Citrog. 22:151, 156. February, 1937.

1 to 2¼ hours, according to the weather. Therefore, measurements were made at approximately the same early hour each morning measured.

The circumferences of the 40 fruits measured in each plot were aver-

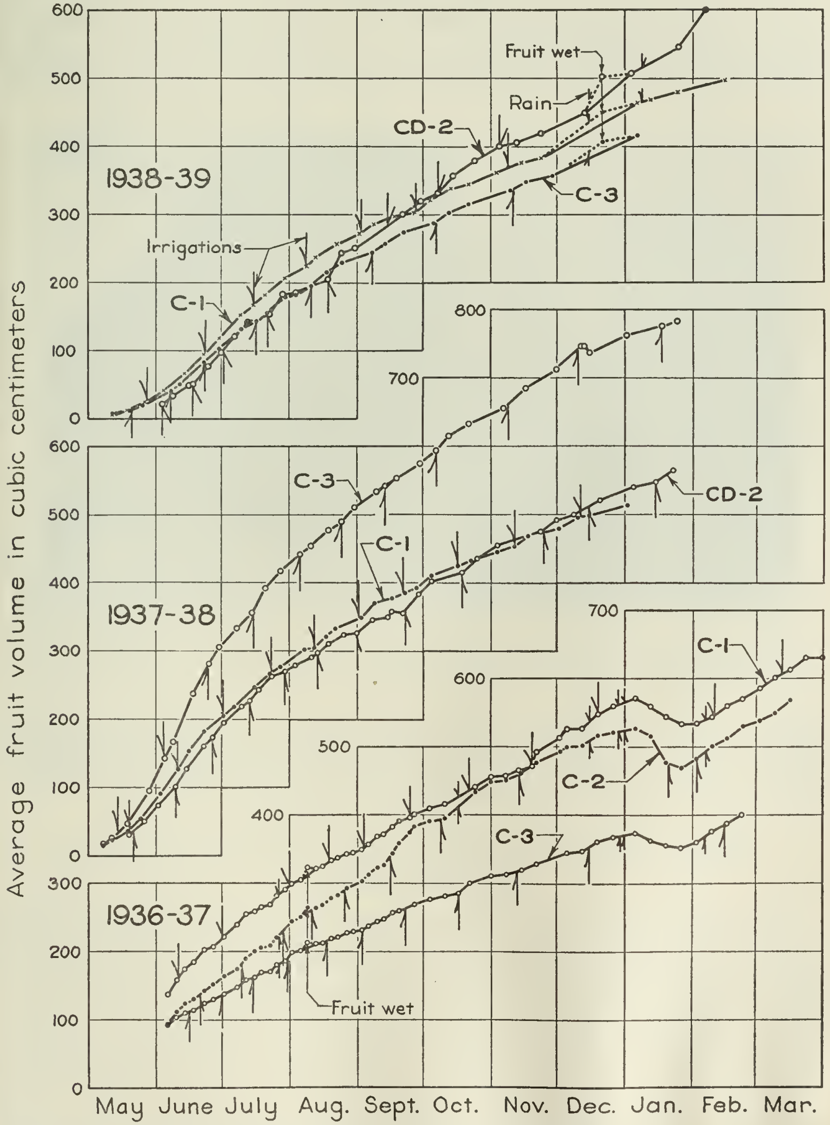

Fig. 5.—Average growth of grapefruit in cubic centimeters volume (assuming fruit spherical) of 40 tagged fruits (10 on north side of each of four trees) in each plot. Measurements calculated from circumference. Long arrows indicate dates of irrigation. Short arrows indicate dates that rains, which penetrated below the mulch, started.

aged. The average circumference thus obtained was converted to volume in cubic centimeters, assuming the fruit to be spheres. These data were plotted as shown in figure 5.

In the freeze of January, 1937, the trees in all plots were entirely defoliated. Fruit also shrank during this period as shown in figure 5. Growth was later resumed, but was apparently a puffing of the skin. Figure 6*A* shows a tree in C–3 in February, 1937; the same plot on March 22 is shown in *B*. The soil-moisture curves showed a loss of moisture per month of 3 to 5 inches depth while the trees were entirely defoliated. Obviously, this must have been essentially loss by slow drainage.

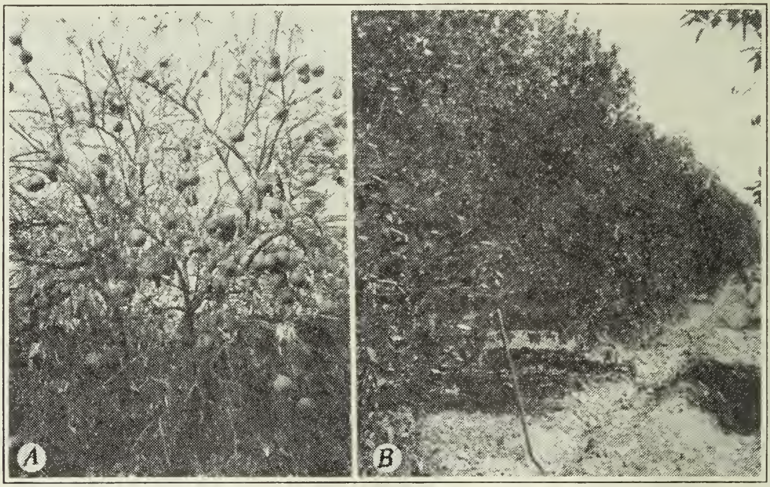

Fig. 6.—*A*, Defoliation of grapefruit tree, plot C–3, following the freeze of January, 1937. The picture was taken February, 1937. *B*, New leaves on grapefruit trees, plot C–3, March 22, 1937.

RESULTS OF SOIL-MOISTURE INVESTIGATIONS IN VINEYARDS

Soil-moisture investigations were conducted through 1937 and 1938 in a plot in a vineyard in the Oasis district. The age of the Thompson Seedless (Sultanina) grapevines was not known, but they were fully mature. Vines were spaced 8 feet in the rows with the rows 10 feet apart. The plot was practically weed-free at all times although there were only one to two cultivations per year. In early years the vineyard was not fertilized, but commercial fertilizers were used during the experiment. Two pounds ammonium phosphate per vine was applied in February, 1938. The soil characteristics are given in table 11.

This vineyard is typical of those in the Oasis district above the alkali

TABLE 11

MOISTURE EQUIVALENT, PERMANENT WILTING PERCENTAGE, AND APPARENT SPECIFIC GRAVITY FOR A VINEYARD PLOT AT VARIOUS DEPTHS; SOIL, COACHELLA FINE SAND, SMOOTH PHASE

Soil characteristics	0–3 foot depth	3–6 foot depth	6–9 foot depth
Range of moisture equivalent, per cent*	7.7–7.8	13.3–13.4	7.7–7.9
Average moisture equivalent, per cent	7.8	13.4	7.8
Permanent wilting percentage	2.2	2.6	2.6
Apparent specific gravity:			
March, 1937 to March, 1938	1.38	1.46	1.33
April, 1938 to February, 1939	1.38	1.47	1.32

* The range for moisture equivalent is based on three sets of composite samples.

TABLE 12

TRANSPIRATIONAL SOIL-MOISTURE LOSSES IN EQUIVALENT INCHES DEPTH IN A GRAPE PLOT, AND PER CENT LOSS AT EACH DEPTH FOR THE TOTAL PLOT RECORD

Interval of record	Equivalent inches loss at the given depths			Total	30-day equivalent*
	0–3 feet	3–6 feet	6–9 feet		
1937					
March 19 to April 28	2.12	0.00	0.00	2.12	1.6
April 28 to May 15	2.48	0.00	0.00	2.48	4.4
May 15 to June 7	3.16	1.40	0.00	4.56	5.9
June 7 to July 3	4.95	2.25	0.57	7.77	9.0
July 3 to July 30	4.35	2.00	0.45	6.80	7.6
July 30 to August 24	4.58	2.00	0.54	7.12	8.5
August 24 to September 17	3.77	0.80	0.00	4.57	5.7
September 17 to October 1	1.00	0.72	0.10	1.82	3.9
October 1 to November 1	1.59	1.58	0.20	3.37	3.3
November 1 to December 1	0.55	0.74	0.18	1.47	1.5
December 1 to January 1	0.12	0.33	0.18	0.63	0.6
1938					
January 1 to February 1	0.00	0.14	0.12	0.26	0.3
February 1 to February 18	0.00	0.04	0.05	0.09	0.2
February 18 to March 23	0.61	0.00	0.21	0.82	0.7
March 23 to April 21	1.95	0.00	0.00	1.95	2.0
April 21 to May 23	3.10	1.73	0.23	5.06	4.7
May 23 to June 15	3.43	1.45	0.00	4.88	6.4
June 15 to July 8	4.40	3.15	0.39	7.94	10.4
July 8 to August 4	3.75	2.35	0.00	6.10	6.8
August 4 to September 7	4.21	2.63	0.86	7.70	6.8
September 7 to October 20	4.41	1.10	0.00	5.51	3.8
October 20 to December 1	2.27	1.16	0.26	3.69	2.6
December 1 to January 1	0.41	0.28	0.13	0.82	0.8
1939					
January 1 to February 18	0.88	0.00	0.08	0.96	0.6
Per cent loss at each depth	66	29	5	....	....

* Equivalent total loss in inches depth for a 30-day period.

belt. Grapes in this small area ripen earlier than in any other section of the United States and usually command a high price for that reason. They are sold fresh. The fruit is normally picked in June. Picking season lasts 3 to 5 weeks.

TABLE 13

TRANSPIRATIONAL USE OF WATER AND ADJUSTED AMOUNTS OF WATER APPLIED IN EQUIVALENT INCHES DEPTH IN GRAPE PLOT*

Months	Years		Average	Water applied, average
	1937–38	1938–39		
March	1.0	1.0	1.0	1.2
April	1.8	2.8	2.3	2.8
May	5.1	5.1	5.1	6.3
June	8.2	8.4	8.3	10.2
July	7.8	7.7	7.8	9.6
August	7.9	6.8	7.4	9.1
September	4.9	4.5	4.7	5.8
October	3.3	3.4	3.4	4.2
November	1.5	2.5	2.0	2.5
December	0.6	0.8	0.7	0.9
January	0.3	0.6	0.4	0.5
February	0.4	0.6	0.5	0.6
Total	42.8	44.2	43.6	53.7

* Irrigation efficiency averaged 80 per cent.

As with other plots, sufficient water was applied at times to bring the bottom sampling zone (6–9 feet) above the moisture equivalent. The periods involved were May 23 to August 26, 1937, and April 21 to August 27, 1938. However, occasional sampling down to dry soil indicated that the actual amount of drainage was small. Therefore, all records, as shown in table 12, are used.

TABLE 14

PERCENTAGE OF TOTAL TRANSPIRATIONAL USE IN GRAPE PLOT BY DEPTH, INDICATING ROOT DISTRIBUTION

Year	0–3 foot depth	3–6 foot depth	6–9 foot depth
1937–38	67	27	6
1938–39	65	31	4
Average	66	29	5

Records of transpirational use and water applied are given in table 13. These show an average total annual transpirational use of about 3½ feet depth, and total applications of about 4½ feet per year. Irrigation efficiency was about 80 per cent. The root distribution is shown in table 14. Note that two thirds of the average root activity is in the top 3 feet below the mulch.

No growth measurements were made for noting any response to soil-moisture conditions. Judging from the soil-moisture records, there was readily available moisture in the soil at all times.

The plot was irrigated by flooding, although the vineyard as a whole was irrigated with furrows. Because of the good growth obtained in the plot the owner changed to basin irrigation for the entire block in which the plot was located. He believes he obtained definitely better yields and quality, but increased the amount of water applied.

Not all vineyardists in the Valley attempt to keep the soil moist at all times after picking. Two or three irrigations are usually applied. No work has been undertaken in this region to determine whether periods when the vines tend to wilt after picking affects future yields.

EFFECTIVENESS OF IRRIGATION TREATMENTS IN CONTROLLING THE CONCENTRATION OF SALTS IN THE SOIL SOLUTION

Many investigations and examples in practical agriculture have demonstrated the necessity of preventing excessive accumulations of salts in that part of the soil occupied by roots.[22, 23] Irrigation waters usually contain dissolved salts, and plant roots remove moisture leaving a greater part of the salts in the soil. It follows that soil moisture will eventually become highly concentrated with salts unless: (1) the salts are precipitated out of solution, (2) they are flushed off by water flowing over the surface of the ground, or (3) they are leached below the root zone by slightly excessive irrigations or rain water.

Rainfall is usually insufficient in Coachella Valley to provide natural leaching, so leaching must be a result of irrigation practice. In the absence of a high water table, it is not believed that salts, except possibly those near the surface, can be removed by surface flushing. Without leaching by irrigation, whether accidental or planned, salts should therefore be expected to accumulate in the root zone.

So far as facilities and funds were available, determinations were made of the salt constituents in the soils of the sampling plots.[24] In the summer

---

[22] Eaton, Frank M. Significance of salt in Coachella Valley agriculture, 1937. 14th Ann. Rept. of the Date Growers' Institute, Coachella, Calif.

[23] Scofield, Carl S. The salinity of irrigation water. Smithsonian Institution Ann. Rept., 1935:275–87.

[24] Water extracts of the oven-dry soil were made by O. C. Compton. From those he made all determinations of anions and specific electric conductance. Analyses of cations in the extracts were made by Bert M. Laurance, Associate in the Experiment Station, Citrus Experiment Station.

TABLE 15

Chemical Analyses of 1:5 Water Extracts of Oven-Dry Soils from Sampling Plots

Date sampled	Depth of samples, feet	Milligram equivalents per kilogram of dry soil							
		Ca	Mg	Na	CO_3	HCO_3	Cl	SO_4	NO_3
		Plot D-2 (Dates)							
May 15, 1936............	0–2	....	....	....	0.0	6.2	0.4	26.7	....
	2–4	....	....	....	0.0	3.9	1.0	23.4	....
	4–6	....	....	....	0.0	4.8	1.4	26.4	....
	6–8	....	....	....	0.0	4.4	1.4	30.2	....
September 22, 1938.....	0–2	8.0	3.9	1.7	0.0	10.0	0.3	4.9	0.05
	2–4	63.6	0.8	4.2	0.0	5.7	0.9	59.2	0.04
	4–6	114.0	0.8	26.9	0.0	6.7	3.2	132.7	0.46
	6–8	29.0	0.8	15.4	0.0	4.9	2.5	34.1	0.71
February 27, 1939......	0–2	7.5	2.0	1.7	0.0	8.3	0.3	4.5	0.08
	2–4	61.0	0.8	5.1	0.0	6.1	0.1	58.0	0.09
	4–6	6.2	0.8	19.8	0.0	5.5	1.8	71.8	0.50
	6–8	53.5	0.8	23.2	0.0	5.5	3.4	63.4	1.35
		Plot D-9 (Dates)							
September 25, 1936....	0–2	....	....	....	0.0	6.2	0.1	6.0	....
	2–4	....	....	....	0.0	6.5	1.1	6.4	....
	4–6	....	....	....	0.6	5.9	0.3	3.7	....
	6–8	....	....	....	0.6	5.0	0.0	1.5	....
December 13, 1938......	0–2	3.2	5.4	1.2	0.0	6.7	0.4	2.8	0.04
	2–4	4.8	5.2	0.8	0.0	5.9	0.4	4.7	0.05
	4–6	6.0	1.2	1.8	0.0	5.5	0.3	2.7	0.11
	6–8	6.5	6.2	1.6	0.0	5.5	0.8	7.3	0.16
		Plot D-10 (Dates)							
September 26, 1936.....	0–2	....	....	....	0.0	3.9	0.0	2.4	....
	2–4	....	....	....	0.0	4.4	0.0	2.5	....
	4–6	....	....	....	0.0	5.0	0.0	2.6	....
	6–8	....	....	....	0.0	3.9	0.0	1.4	....
February 28, 1939.......	0–2	5.0	3.1	1.2	0.0	5.5	0.4	2.2	0.05
	2–4	4.5	2.5	1.7	0.0	5.7	0.4	2.4	0.09
	4–6	7.2	3.6	1.6	0.0	6.9	0.4	5.2	0.28
	6–8	4.8	3.4	0.8	0.0	5.3	0.4	2.6	0.07
		Plot CD-2 (Dates and grapefruit)							
January 15, 1937........	0–2	....	....	....	0.0	8.0	2.4	2.7	....
	2–4	....	....	....	4.8	10.4	0.6	4.7	....
	4–6	....	....	....	4.8	9.8	1.0	8.1	....
	6–8	....	....	....	3.6	10.1	1.7	16.8	....
September 21, 1938.....	0–2	3.0	3.3	4.1	0.0	8.1	0.3	2.2	0.03
	2–4	9.0	2.0	16.5	0.0	5.3	0.8	19.8	0.05
	4–6	27.5	1.6	10.5	0.0	4.1	0.9	34.8	0.02
	6–8	12.0	1.2	15.0	0.0	4.5	1.3	21.7	0.10
December 12, 1938......	0–2	5.5	1.8	2.0	0.0	7.1	0.3	2.2	0.03
	2–4	11.5	1.2	15.7	0.0	5.3	1.3	22.2	0.04
	4–6	22.5	1.3	9.1	0.0	4.1	0.9	29.4	0.03
	6–8	11.2	0.8	14.3	0.0	4.1	1.1	20.3	0.05

TABLE 15—*Continued*

Date sampled	Depth of samples, feet	Milligram equivalents per kilogram of dry soil							
		Ca	Mg	Na	CO_3	HCO_3	Cl	SO_4	NO_3
		Plot C-1 (Grapefruit)							
May 28, 1936	0–2	....	....	....	0.0	4.2	0.0	1.3	....
	2–4	....	....	....	0.0	5.3	0.0	1.7	....
	4–6	....	....	....	0.0	4.2	0.0	1.3	....
	6–8	.....	....	....	0.0	3.9	0.0	1.0	....
March 8, 1939	0–2	5.0	1.0	1.2	0.0	5.5	0.4	1.8	0.02
	2–4	4.2	0.8	1.4	0.0	5.1	0.4	1.7	0.02
	4–6	4.0	trace	1.0	0.0	3.8	0.3	1.0	0.02
	6–8	4.0	trace	1.1	0.0	4.3	0.3	0.8	0 02
		Plot C-2 (Grapefruit)							
February 20, 1939	0–2	4.0	2.5	3.1	0.0	6.3	0.8	2.6	0.03
	2–4	3.0	2.8	3.1	0.0	5.5	0.9	1.9	0.02
	4–6	3.0	2.0	1.9	0.0	4.5	0.8	1.3	0.02
	6–8	2.5	3.7	3.3	0.0	6.9	0.9	1.3	0.02
		Plot C-3 (Grapefruit)							
May 21, 1936	0–2	....	....	....	0.6	5.3	0.1	3.4	....
	2–4	....	....	....	0.6	5.0	1.2	3.8	....
	4–6	....	....	....	0.6	3.9	5.1	6.1	....
	6–8	....	....	....	....	3.3	0.7	1.2	....
March 3, 1939	0–2	3.0	3.0	1.0	0.0	5.1	0.4	1.5	0.03
	2–4	4.5	1.0	1.0	0.0	4.9	0.3	1.1	0.05
	4–6	3.2	3.8	2.0	0.0	4.7	0.8	3.3	0.09
	6–8	3.0	1.2	1.2	0.0	3.8	0.4	1.0	0.06
		Plot V-2 (Grapes)							
March 21, 1938	0–3	....	....	....	0.6	6.2	0.0	5.8	....
	3–6	....	....	....	0.0	4.6	1.6	7.1	....
	6–9	....	....	....	0.0	4.2	1.7	3.4	....
December 17, 1938	0–3	2.5	4.1	2.0	0.0	5.7	0.5	2.0	0.03
	3–6	7.0	1.1	8.6	0.0	5.9	2.7	3.8	0.03
	6–9	4.5	1.8	4.8	0.0	4.9	3.0	3.2	0.04

of 1938 analyses were made of 1:5 water extracts of composite samples (10 holes) obtained from May, 1936, to April, 1938. The concentration of anions in the first set of samples from each plot was determined, and specific electric conductance was measured for all samples. In the summer of 1939 complete analyses were made of 1:5 water extracts of com-

TABLE 16

CHEMICAL ANALAYSES OF WATER FROM WELLS USED IN IRRIGATING PLOTS[*]

Plot and well no.[†]	Date collected	Temp. °F	pH	$K \times 10^5$ at 25° C	Boron, p.p.m.	Per cent Na	Per cent Cl	Milligram equivalents per liter							
								Ca	Mg	Na	CO_3	HCO_3	SO_4	Cl	NO_3
Plots D-1 and D-10:															
5-7-21a	April 19, 1938	..	7.90	30.2	0.04	40	10	1.40	0.52	1.27	trace	2.45	0.32	0.25	0.05
5-7-21b	Dec. 27, 1937	..	7.80	29.6	0.04	31	12	1.69	0.45	0.94	trace	2.27	0.49	0.35	0.01
Plot D-2:															
5-7-28c	Aug. 4, 1938	74	7.97	40.8	0.05	34	12	2.28	0.58	1.46	trace	3.12	0.53	0.50	0.07
Plot D-9[‡]															
5-6-22b	July 13, 1938	75	8.10	109.0	0.35	44	19	4.86	1.08	4.76	0	3.14	4.51	2.06	1.20
5-6-22c	July 13, 1938	70	8.24	35.1	0.03	33	17	1.81	0.47	1.20	trace	2.25	0.12	0.60	0.60[§]
Plot CD-2:															
6-7-1a	July 18, 1938	72	8.37	32.2	trace	31	14	1.93	0.32	1.03	trace	2.21	0.58	0.46	0.06
6-7-1b	Jan. 13, 1939	72	7.75	28.7	trace	37	11	1.59	0.27	1.11	..	2.22	0.38	0.34	0.12
Plot C-1:															
6-7-4a	July 18, 1938	70	7.63	26.2	0.03	36	12	1.46	0.25	0.95	0	1.88	0.44	0.32	0.05
6-7-4b	July 15, 1938	73	7.97	29.0	trace	42	13	1.58	0.19	1.26	trace	1.92	0.56	0.39	0.07
Plot C-3:															
5-7-34a	July 19, 1938	73	7.70	92.1	0.02	33	17	5.27	1.08	3.15	0	3.62	3.67	1.59	0.75
5-7-34b	July 19, 1938	73	8.13	35.4	0.02	39	15	1.87	0.35	1.39	0	2.34	0.39	0.51	0.11
Plots V-1 and V-2:															
7-8-34a	July 18, 1938	94	9.38	35.4	0.07	87	28	0.45	trace	2.92	0.72	0.60	1.07	0.93	trace

---

[*] Analyses by V. P. Sokoloff, Citrus Experiment Station, and U. S. Bureau of Plant Industry, Riverside, Cal.

[†] Well numbers designate township, range, and section.

[‡] Plot irrigated principally from well 5-6-22c.

[§] Later analyses showed 0.08 and 0.10 milligram equivalents per liter, respectively, for the NO_3 in this water.

posite samples (10 holes) obtained in the fall and winter of 1938–39. The data, except for the conductance measurements, are given in table 15.

All plots are included whether or not eliminated from use summaries because of restricted drainage. The data are presented on an oven-dry soil basis, and may be converted to parts per million on a dry-soil-weight basis by multiplying by the following factor indicated for each ion: CO_3,30.0, HCO_3,61.0, Cl,35.5, SO_4,48.0, NO_3,62.0, Ca,20.0, Mg,12.2, Na,23.0. These data indicate the composition and concentration of the salt content of the soil. Conductance determinations substantiate the data of table 15.

Table 16 lists analyses of water from wells used to irrigate the various plots.

The period of the investigations was too short, and variations in salt concentrations because of soil differences were too great, to determine whether or not salt accumulated in the soil during that period. However, the low salt concentrations found indicate that there are no serious salt accumulations in any of the plots. The exceedingly low concentrations in some of the sandier soils indicate excessive leeching.

PRESENT APPLICATIONS OF WATER ON FARMS

Methods of Measurement.—Records have been obtained of the amounts of water applied on 56 farms scattered over the Valley. A few of these are actually groups of farms operating under one community irrigation system for which records of individual farms were not available. Length of the farm records varies from one to eight years. An attempt was made to get good representation of the Valley agriculture, but the farms included may be, as a whole, above the average for the Valley in yields and returns.

The method utilized was to test the pumping plant for discharge, horsepower input, head, and efficiency, and to compute the quantity of water pumped from monthly records of electric energy consumed. Where possible, records of hours run were obtained which provided a check against power consumption and permitted segregation of use by crop. On one large farm it was the owner's practice to make monthly weir measments of discharge from each of four pumps and to keep records of hours of irrigation of each planting. These records were utilized.

The local power company, the Nevada California Electric Company, maintains a pump-testing service. Their records of pump tests were made available, and 101 of them were utilized. Most of these tests were made using a transverse Pitot tube through the discharge pipe to determine flow. Ten-point traverses were made. These measurements are normally fairly accurate, but tend to be somewhat high if gas is present in the water or if the flow is turbulent.

To check the accuracy of the power companies' tests and to obtain as many additional tests as possible, pumps were tested whenever there was free time. There were 38 such tests made using field weirs or a special 3-inch Parshall measuring flume; 18 tests made using a transverse Pitot tube; and 2 tests made timing the filling of a tank of known size. Velocity of approach could not always be eliminated from weir measurements. It was checked with a current meter, and in the few cases where it was measurable, proper corrections were made. Input was determined by timing the rate of rotation of the electrical watt-hour meter disk with a stop watch. Pumping depths were measured, whenever possible, with an electrical sounding line. In some cases, air lines were utilized. Head above the pump was measured directly in a standpipe or by using a pressure gauge which had been tested for accuracy. All readings were carefully checked before each test was completed.

Irrigation systems on some farms were such that the head on the pump varied considerably with the point of discharge. Where separate records were not kept on individual plantings, the following was the procedure:

1. If average pump discharge and power input were too uncertain, the farm was not included.
2. If differences in head were moderate, an attempt was made to test the pump under approximately an average lift.
3. On three occasions tests were made under each extreme and an average arrived at through estimating the proportion used at each elevation of discharge from the pipe line.

On many of the farms all electricity used was measured through one meter. This made it necessary to select farms which had a separate meter for the pumping plant, or on which only a minor portion of the energy was utilized for domestic or other purposes. In the latter case allowances were made for energy used for those other purposes.

Each farm was visited at least twice a year to determine net acreage of each class of crop. Normally, detailed surveys were not made, but the owners' estimates were obtained. These were checked against the 1936–37 crop survey, and against the total assessed acreage with deductions for acreage of yards, roads, area covered by buildings, and undeveloped land. Where there still remained question as to accuracy, traverses were made by counting rows and measuring spacing of rows, or by utilizing a special device on a car which recorded distances in feet. It was necessary to calibrate this device against known distances each day used.

Significant calculations are not feasible as to the possible proportions of any errors in these records. Judging from the accuracy of the various factors involved, including seasonal change in pumping lift, it appears possible that the maximum error in any one individual record could approach 20 per cent. As a rule, maximum error may easily be between 5 and 10 per cent in any one record. However, the work was planned and conducted so as to prevent such errors from accumulating, and errors in the averages are not believed to exceed these latter limits.

Classes of Crops.—So far as practicable, records were segregated according to crop. This was not feasible in the case of the various truck crops (including onions and sweet potatoes) as they grow quickly and plantings may be changed several times a year. Further, several different crops are normally grown on one field and no segregation made of the irrigation of each. Truck crops are therefore included as one item.

For the greater part of the farms having more than one crop, it was not feasible to segregate the amount of water applied to each different crop. Such records are all tabulated together under "mixed crops." If nothing more, they provide a check on the segregated records.

For the most part the designations given the crops are self-explanatory. The citrus is predominantly Marsh Seedless grapefruit, although tangerines are included. Tangerines are decreasing in acreage. Grapes are grown for table use. There are some Malagas, but Thompson Seedless is the predominating variety.

Those crops classed as "truck" are essentially vegetables grown to be marketed fresh in the fall, winter, and spring. They include, somewhat in order of their importance: tomatoes, beans, peas, summer squash, Italian squash, corn, peppers, carrots, okra, and lettuce. Acreage of each fluctuates exceedingly from season to season. Some varieties of beans and peas are grown in the fall essentially as a covercrop, the beans sometimes not even being picked. Spring onions (Crystal Wax and Bermuda) are extensively grown, as are sweet potatoes to a lesser extent, and are included as truck.

Most truck is not grown through the summer, the land normally being fallow at least two months (usually July and August). Sweet potatoes and okra are, however, grown through that season. Some land is made to produce two crops a year, one planted in September and one in January or February.

Sufficient records of truck were obtained to get a fair representation of all types of vegetables grown and a fair representation of land both double- and single-cropped. Information was gathered as to the acreage of each crop and as to the frequency of cropping to make sure of obtaining an adequate cross section.

Summary of the Records.—Table 17 shows the extent of the present application records. Because of the variation in length of records on individual farms, and because of acreage changes on many farms, the data for each farm for each month were treated as an individual record; and summarized on that basis. In table 17 the total acres of each crop, taken from the crop survey, is given to show the extent of the crop in the Valley. Other data in the table indicate how well each crop is represented.

Included in the crops are two classifications for records that could not be completely segregated (mixed crops and mixed orchard). The last column in table 17 gives the distribution of individual crops included in mixed crops. Using the average annual application found for each separate crop and proportioning that to mixed crops according to acreage, the average annual application of water would be 73 inches in depth. This is in good agreement for the average application on the farms of mixed crops which is 68 inches in depth.

TABLE 17

SUMMARY SHOWING EXTENT OF RECORDS OBTAINED OF WATER NOW APPLIED TO IRRIGATE FARMS IN COACHELLA VALLEY

Crop	Total acres in area 1936–37	Extent of data obtained					
		Acres times years of record	Gross number of farms*	Gross number of annual records†	Average years per farm	Average acres per farm	Acres times years for "mixed crops"
Alfalfa	1,440	757	4	12	3.0	63	35
Cotton	1,460	919	4	8	2.0	115	51
Citrus	2,460	1,461	4	27	6.4	55	226
Dates	2,640	1,894	12	49	4.1	39	333
Dates under four years	......‡	75	1	5	5.0	15	......
Citrus and dates interplanted	550	416	2	7	3.5	63	59
Truck crops	3,660	1,325	17	40	2.4	29	1,056
Vineyard	2,280	814	4	8	2.0	90	197
Mixed crops (including all listed above)	......‡	2,028	14	45	3.1	46	......
Mixed orchard (citrus and dates)	......‡	340	2	7	3.5	75	......
Other crops (no records):							
Figs, pecans, peaches	100	......	..	..	...	..	34
Pasture and grain	670	......	..	..	...	..	37
"Part" pasture§	470	......	..	..	...	..	0
Total	15,730	10,029	64	208	...	..	2,028

* Some "farms" are actually several farms operating under one irrigation system.

† Number of farms times number of monthly records divided by 12.

‡ Acreage included elsewhere.

§ Uncultivated land over which water from artesian wells flows uncontrolled to provide a certain amount of pasture.

Table 18 gives the average application of water in inches depth by months and the monthly percentage of the total annual application for each crop. Variation of individual records is shown in table 19, as well as maximum and minimum annual records.

Variation of individual records can be accounted for in several ways. Truck, of course, includes many vegetables requiring differing irrigation practices, and wide variations are to be expected. The citrus classification includes plantings different in age, size of trees, and vigor of growth. Possibility of about a 10 per cent error in the records may account for some of the variations found. Sometimes only relatively small heads of water are available, often the soils are extremely pervious, and with the necessity of using inexpensive methods of irrigation it may be difficult to

TABLE 18

Averages from Records Obtained of Amounts of Water Now Applied in Irrigation of Coachella Valley Farms

Month	Alfalfa		Cotton		Citrus		Dates		Dates under four years	
	Inches depth	Per cent of total	Inches depth	Per cent of total	Inches depth	Per cent of total	Inches depth	Per cent of total	Inches depth	Per cent of total
January	2.3	2	0.0	0	2.3	2	3.9	4	0.5	1
February	5.8	6	0.0	0	4.1	4	5.2	5	1.2	3
March	7.5	8	3.3	6	5.7	6	7.6	7	3.8	8
April	9.1	10	3.4	6	8.2	8	10.3	10	6.3	13
May	11.7	12	1.5	3	11.3	11	12.0	11	5.5	11
June	11.1	12	4.0	7	12.8	13	13.1	12	5.4	12
July	13.6	14	10.8	19	15.2	15	14.6	14	5.9	12
August	9.9	10	13.9	25	15.4	16	13.4	13	5.6	12
September	10.3	11	13.6	24	11.0	11	12.2	12	6.0	13
October	6.3	6	5.7	10	7.5	8	6.4	6	3.6	8
November	6.2	6	0.0	0	4.3	4	4.0	4	2.3	5
December	2.5	3	0.0	0	1.6	2	2.7	2	0.8	2
Total	96.3		56.2		99.4		105.4		47.0	

Month	Citrus and dates interplanted		Truck crops		Vineyard		Mixed crops		Mixed orchard (citrus and dates)	
	Inches depth	Per cent of total	Inches depth	Per cent of total	Inches depth	Per cent of total	Inches depth	Per cent of total	Inches depth	Per cent of total
January	6.9	6	3.0	5	1.0	2	2.6	4	3.9	5
February	3.2	3	4.0	7	5.2	10	3.9	6	3.9	5
March	8.6	7	4.5	8	4.7	9	5.3	8	4.9	6
April	11.0	9	7.1	12	5.4	11	7.3	11	6.0	8
May	11.6	10	9.4	16	8.3	16	8.7	12	4.9	6
June	14.4	12	6.8	11	7.3	14	7.6	11	7.5	9
July	15.0	13	3.0	5	5.9	12	6.4	9	11.6	15
August	13.4	12	1.3	2	6.4	13	5.5	8	12.9	16
September	12.3	11	5.5	9	4.5	9	7.6	11	10.7	13
October	8.0	7	5.7	9	0.9	2	6.1	9	7.1	9
November	5.0	4	5.3	9	0.6	1	4.8	7	3.8	5
December	6.9	6	4.4	7	0.6	1	2.5	4	2.2	3
Total	116.3		60.0		50.8		68.3		79.4	

TABLE 19

DISTRIBUTION OF RECORDS OBTAINED OF WATER NOW APPLIED

Crop	Number of records segregated according to total annual applications in inches depth																		Inches depth	
	30 or under	30.1 to 40	40.1 to 50	50.1 to 60	60.1 to 70	70.1 to 80	80.1 to 90	90.1 to 100	100.1 to 110	110.1 to 120	120.1 to 130	130.1 to 140	140.1 to 150	150.1 to 160	160.1 to 170	170.1 to 180	Over 180	Total records	Maximum record	Minimum record
Alfalfa	..	..	..	2	1	1	1	1	1	1	..	1	2	..	..	..	..	11	145	57
Cotton	1	..	1	2	2	2	..	..	..	..	..	..	..	..	..	..	..	8	78	28
Citrus	..	..	2	..	..	3	1	6	3	4	2	..	..			1	2	24	221	44
Dates	..	..	..	1	6	8	6	6	4	..	4	2	1	5	4	2	..	49	180	60
Dates under four years	..	2	1			1	1	..	..	..	..	..	..	..	..	..	..	5	85	32
Citrus and dates interplanted	..	..	..			..	..	1	2	1	2	..	1	..	..	..	..	7	143	92
Truck crops	1	1	7	7	12	6	2	..	..	1	..	..	..	..	..	..	..	37	113	29
Vineyard	..	3	2	1	1	1	..		..	..	..	..	..	..	..	..	..	8	71	35
Mixed crops	1	6	6	6	9	3	1	1	..	2	2	1	4	..	..	..	..	42	150	24
Mixed orchard (citrus and dates)	..	..	..	1	2	1	..	2	1	..	..	..	..	..	..	..	..	7	101	53

obtain good distribution efficiency. In other words, to get sufficient water at the far end of a field it may be necessary to apply excessive amounts nearer the point of delivery. Variation of these conditions from farm to farm will largely account for the variations in application.

CROP AND WELL SURVEY

Through the winter and spring of 1936–37 a crop and well survey was made of the Valley in coöperation with the Coachella Valley County Water District. That agency prepared block maps of agricultural land within the Valley (using their regular assessment record sheets, one land section to scale of 1 inch = 600 feet on each sheet). Assessed acreage was shown for each parcel of property. The area included was east of Range 6 East, west of Range 10 East, and north of the Riverside County line, and within the Valley proper.

That organization then provided a man to do the field work. The procedure was to call at each farm and to obtain as good information as possible concerning crops and net acreages. Then the boundaries of each crop classification were sketched on the maps. Normally these boundaries were located by traversing two sides of a field with a car and interpolating distances as close as possible to 1/100 of a mile with the speedometer. Since farms are normally regular subdivisions of sections, and since each farm is usually divided up in a uniform fashion, it was relatively easy to sketch in approximate crop boundaries without a great deal of survey work. Acreages are net, that is, include only actual areas planted to crops and exclude farm roads and other unplanted areas. Data were obtained on acreage of land occupied by buildings, yards, roads, etc., as well as in crops. Wells were spotted on the maps, and symbols were used to designate type of pump and type of prime mover.

The field sheets were checked by the author. Owners' acreage estimates were compared with the field plotting and with the total assessed acreage. Any significant discrepancies were investigated in the field. Further, about 20 per cent of the sheets were thoroughly checked in the field.

All data were then summarized and tabulated and a crop and well map was drawn to a scale of 1 inch to 2,000 feet. It is approximately 5 × 8½ feet in size. The various crops are distinguished by symbols, as are the several types of wells.

Crop data are summarized by townships as shown in table 20. Accuracy was such that errors should not exceed about 5 per cent.

A summary of the numbers of irrigation wells is shown in table 21.

Total "Draft" on Ground Waters.—Using the average data obtained for water applied to various crops and the total acreage of each crop it has been possible to estimate roughly the total annual amount of irriga-

TABLE 20

CROP ACREAGE OF COACHELLA VALLEY, CALIFORNIA, SURVEYED WINTER AND SPRING OF 1936–37

Township	Alfalfa	Cotton	Citrus	Dates	Citrus and dates inter-planted	Figs	Truck crops	Table grapes	Pecans	Pas-ture*	Total
Land in Improvement District No. 1											
T4S, R6E	115	0	65	0	0	0	32	10	0	0	222
T4S, R7E	0	0	3	10	0	0	0	0	0	0	13
T5S, R6E	0	0	0	0	6	0	0	0	0	0	6
T5S, R7E	326	625	964	726	160	1	996	260	6	88	4,152
T5S, R8E	156	17	26	28	6	1	78	36	0	5	353
T6S, R6E	0	0	0	20	0	0	0	0	0	0	20
T6S, R7E	306	464	115	663	59	4	456	275	20	70	2,432
T6S, R8E	269	166	62	338	88	2	1,210	389	0	282	2,806
T6S, R9E	0	0	0	0	0	0	0	0	0	0	0
T7S, R7E	10	42	0	1	0	0	112	0	0	0	165
T7S, R8E	110	8	113	187	12	24	240	662	0	168	1,524
T7S, R9E	50	0	110	104	13	0	14	120	0	73	484
T8S, R8E	12	0	574	103	39	1	187	327	0	28	1,271
T8S, R9E	18	19	106	14	2	11	124	124	0	102	520
Total...	1,372	1,341	2,138	2,194	385	44	3,449	2,203	26	816	13,968
Indian land											
T5S, R8E	0	0	0	0	0	0	65	0	0	0	65
T7S, R7E	0	37	0	0	0	0	5	0	0	0	42
T7S, R8E	0	6	1	15	0	4	22	0	0	17	65
T8S, R8E	0	0	0	0	0	0	50	0	0	0	50
T8S, R9E	0	0	0	0	0	0	5	0	0	0	5
Total...	0	43	1	15	0	4	147	0	0	17	227
Land outside Improvement District No. 1											
T4S, R6E	0	0	6	9	0	0	0	2	0	0	17
T5S, R6E	54	76	313	404	167	0	43	75	20	14	1,166
T5S, R7E	0	0	2	22	0	0	2	0	0	0	26
T7S, R9E	10	0	1	0	0	0	0	0	0	28	39
T8S, R9E	0	0	0	0	0	0	14	0	0	26	40
Total...	64	76	322	435	167	0	59	77	20	68	1,288
Grand total....	1,436	1,460	2,461	2,644	552	48	3,655	2,280	46	901	15,483

* Includes half of a total of 470 acres in T6S, R8E; T7S, R8E; and T8S, R9E over which artesian water is allowed to flow irregularly to provide some poor pasturage. It is estimated that irrigation is somewhat effective on about half the acreage.

TABLE 21

Number of Irrigation Wells of Various Classifications in Coachella Valley, Recorded Winter and Spring, 1936–37

Township	Artesian well (no pump)	Centrifugal pump		Deep-well turbine		Total
		Electric-driven	Engine-driven	Electric-driven	Engine-driven	
Land in Improvement District No. 1						
T4S, R6E	0	0	0	1	2	3
T4S, R7E	0	0	0	0	2	2
T5S, R6E	0	0	0	1	0	1
T5S, R7E	0	9	0	112	10	131
T5S, R8E	0	4	0	6	1	11
T6S, R6E	0	0	0	3	0	3
T6S, R7E	0	13	0	62	5	80
T6S, R8E	19	88	8	44	0	159
T6S, R9E	0	0	0	0	0	0
T7S, R7E	0	2	0	1	0	3
T7S, R8E	32	17	3	16	0	68
T7S, R9E	7	12	0	7	0	26
T8S, R8E	3	8	0	24	1	36
T8S, R9E	4	13	2	8	1	28
Total	65	166	13	285	22	551
Indian land						
T5S, R8E	0	1	0	0	0	1
T7S, R7E	0	1	0	0	1	2
T7S, R8E	1	1	8	1	0	11
T8S, R8E	0	0	0	0	0	0
T8S, R9E	0	0	0	0	0	0
Total	1	3	8	1	1	14
Land outside Improvement District No. 1						
T4S, R6E	0	0	0	1	0	1
T5S, R6E	0	2	0	33	1	36
T5S, R7E	0	0	0	1	1	2
T7S, R9E	2	1	0	1	0	4
T8S, R9E	3	0	0	0	0	3
Total	5	3	0	36	2	46
Grand total	71	172	21	322	25	611

tion water applied to lands in the Valley. Since the entire supply is essentially obtained from wells, this total amount is here termed "ground water draft" regardless of the fact that part undoubtedly returns to the water table through deep percolation from overlying irrigated land. On this basis it would appear that the present annual agricultural "draft" was about 100,000 acre feet, including water "circulated" between the ground surface and the water table. Near the Salton Sea there are considerable areas kept ponded during the fall hunting season to attract ducks. Estimates have not been made of the acreage involved or the amount of water used for such purposes. Urban use is not included.

Distribution of "draft" by months is indicated in the following tabulation:

	Per cent
January	3
February	5
March	7
April	10
May	12
June	12
July	13
August	12
September	11
October	7
November	5
December	3

SUMMARY AND CONCLUSIONS

A good part of the work reported herein was concerned with soil-moisture investigations in commercial date and grapefruit orchards and vineyards. Plots were selected on the basis of adaptability to soil-moisture work and on the basis of the apparent productivity of the plantings. Essentially, the cultural practices of the owners were followed and there was no opportunity to use differential treatments. The work was further handicapped by the excessive stratification of the soils of the entire area.

Because rates of soil-moisture loss were found to vary more with the amount of water applied than with any other factor, and moisture in a good part of the soil was above the moisture equivalent at all times, and soil-moisture loss continued at a high rate after trees had been entirely defoliated, it is concluded that a gradual downward movement or drainage of moisture persisted weeks after irrigation in some plots all the time and in all plots some of the time.

To reduce to insignificant proportions any effect of drainage on apparent transpirational use of water, only those records where soil-moisture in the lower depths of sampling was essentially at or below the moisture equivalent (which is assumed to be not higher than the true field capacity of the soils) are utilized in this report.

From preliminary work which involved random soil-moisture sampling all over the Valley, and from records of average present amounts of water applied to all crops, it appears that the usual local irrigation practices are such that a considerable portion of water applied is in excess of plant needs, and drains from the root zone.

Heavy covercrops appear to increase transpirational use of water. In one case, at least, this use was double the average of all other comparable records for a few weeks when an exceptionally heavy covercrop was in its full prime.

Irrigation efficiencies of 80 per cent were obtained with essentially uniform distribution of water over the plots where there was no surface runoff or appreciable drainage. In actual practice, such high efficiency might be hard to attain without excessive labor and investment costs. Some drainage is believed to be essential to keep salt concentrations in the soil below toxic limits.

It appears that 4 to 7 inches of water can be stored in dry soils planted to dates, grapefruit, or grapes in Coachella Valley, without loss of excessive amounts by drainage. This would require application of from 5 to 9 inches depth. Frequency of irrigation can be estimated from the average monthly use shown in the tables in conjunction with the application per irrigation.

As regards dates, the data indicate that the average date planting removes a total of about 6 feet depth of water from the soil annually if moisture is always readily available. With 80 per cent irrigation efficiency this means a total annual application of 7½ feet. This required application may be increased somewhat by exceptionally heavy covercrops, or by lower irrigation efficiency.

Judging root distribution of dates from the relative rates at which moisture is removed at the various depths, an average of about 90 per cent are in the first 4 feet below a 5-inch mulch. An average of 60 per cent are in the first 2 feet. The effective roots of dates, therefore, do not appear to be as deep as previously reported.

As regards grapefruit, applications of water to plots averaged 5 to 7 feet annually. In all cases there was considerable drainage, and in no case was there any evidence of appreciable response of apparent growth rate of fruit to soil moisture. Therefore, the amounts of water necessary are less than the amounts applied in the plantings concerned. Judging from rates of moisture removal, about 85 to 95 per cent of the roots are in the top 4 feet below a 5-inch mulch.

As regards grapes, applications of 4½ feet depth of water annually, with an irrigation efficiency of 80 per cent appear adequate to maintain readily available moisture in the soil at all times. About 65 per cent of the roots, in the plot investigated, were in the first 3 feet of soil below the 5-inch mulch. About 95 per cent were in the first 6 feet.

No soil-moisture work was undertaken with other crops, but records of average present applications are given (table 18). As a matter of judgment, it would appear that average applications of water to all crops is excessive.

Data on present water applications, together with the crop survey (table 20), make possible an estimate of the approximate distribution of total irrigation water use for the Valley by months. These data suggest that there is annually applied in irrigation in the Valley upwards of 100,000 acre-feet of water. But because of excessive applications, a considerable portion is only "circulated," and eventually returns to the ground-water table.

12m-7,'41(1726)